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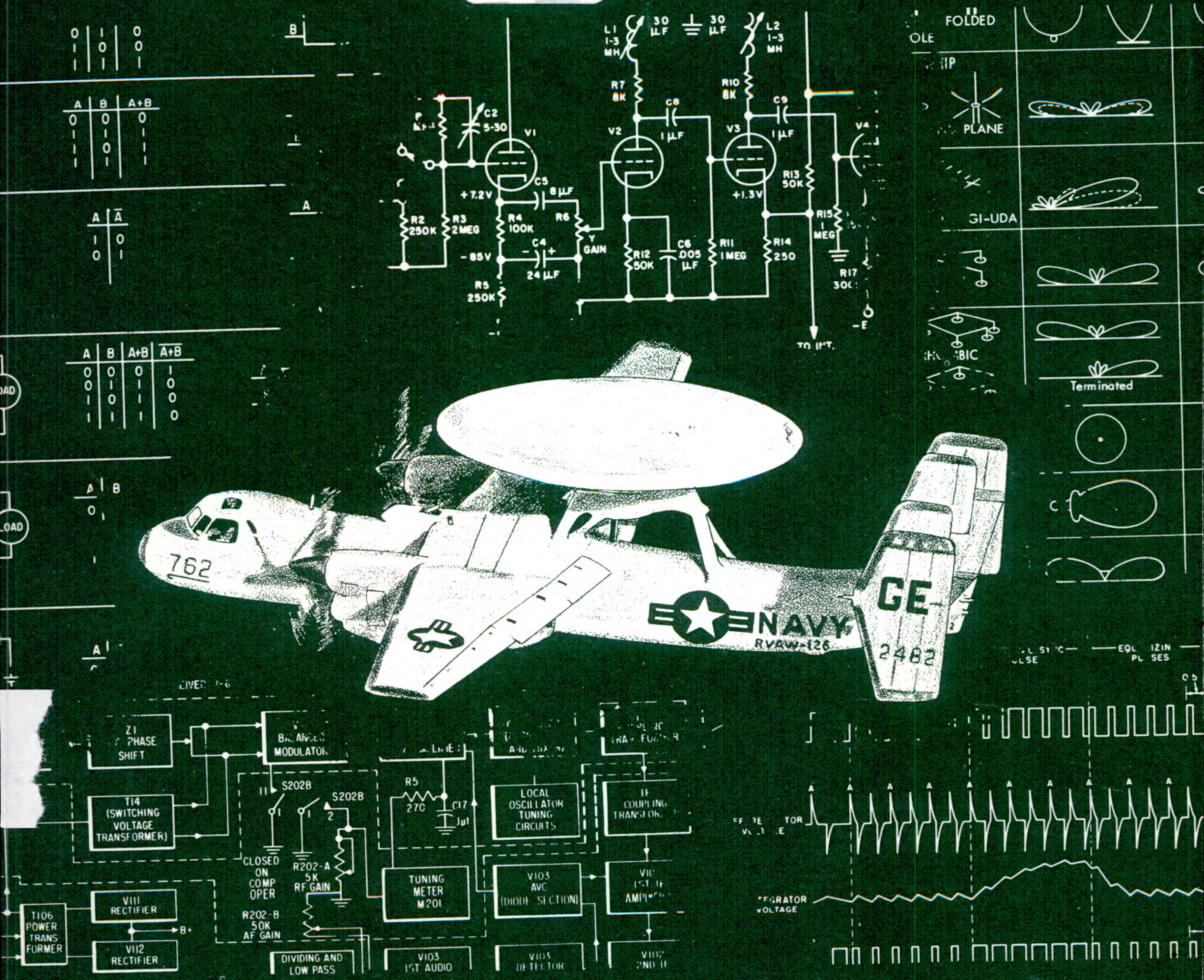

AVIATION

ELECTRONICS TECHNICIAN 3 & 2

BUREAU OF NAVAL PERSONNEL

RATE TRAINING MANUAL NAVPERS 10317-D

PREFACE

This Rate Training Manual is one of a series of training manuals prepared especially for enlisted personnel of the U.S. Navy and Naval Reserve who are preparing for advancement to AT3 and AT2. Since all personnel seeking advancement to these levels are not held responsible for the entire contents of this training manual, a study guide is included.

The Manual of Qualifications for Advancement, NavPers 18068 (Series), has been used as a guide in the selection of content for this training manual. Trainees should become familiar with the qualifications for advancement prior to starting work on this manual.

Of the 21 chapters in this training manual, 20 are concerned with the technical aspects of the AT rating. Chapter 1 contains introductory information with which the trainee should familiarize himself before studying the other chapters.

Basic Electricity, NavPers 10086 (current edition), and Basic Electronics, NavPers 10087 (current edition), contain essential background information for the AT rating. Some U.S. Armed Forces Institute courses, the content of which are closely related to the AT rating, are listed in the Reading List.

This Rate Training Manual has been prepared by the Navy Training Publications Center, NAS Memphis, Millington, Tennessee, for the Bureau of Naval Personnel. Credit is given to the Naval Air Technical Training Center, located at NAS Memphis, Millington, Tennessee, the Naval Examining Center, Great Lakes, Illinois, and the Naval Air Systems Command for technical reviews.

1969 Edition

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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READING LIST

For trainees that have not had high school algebra and trigonometry.

- E 164 Beginning Algebra I
- E 165 Beginning Algebra II

or

- PA 164-165 Beginning Algebra I - II (Programed)

For trainees that have had high school algebra and trigonometry.

- D 166 Advanced Algebra
- D 188 Trigonometry
- E 290 Physics I
- E 291 Physics II
- C 781 Fundamentals of Electricity
- B 788 Introduction to Electronics I
- B 789 Introduction to Electronics II

"Members of the United States Armed Forces Reserve Components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active-duty orders."

STUDY GUIDE

The table below indicates the chapters of this manual which particularly apply to your rate.

Chapter	ATN	ATR
1	3	3
2	3	3
3	3	3
4	3	3
5	3	3
6	3	3
7	3	3
8	3	3
9	3	3
10	3	3
11	3	3
12	3	3
13	3	3
14	3	3
15	2	2
16	3	3
17	3	2
18		3
19	3	3
20		3
21	2	2

CHAPTER 1

AVIATION ELECTRONICS TECHNICIAN RATING

This Rate Training Manual is designed as an aid in preparing for advancement to Petty Officer Third and Second Class Aviation Electronics Technician. It is based primarily on the professional requirements as specified in the Manual of Qualifications for Advancement, NavPers 18068 (Series), through change No. 4. Therefore, subsequent changes in the qualifications may not be reflected in the information given in this training manual.

Most of the contents of this training manual involves the technical subject matter which the Aviation Electronics Technician must become proficient. Other areas covered include maintenance organization, safety, and publications.

ENLISTED RATING STRUCTURE

The present enlisted rating structure consists of general ratings and service ratings.

General ratings identify broad occupational fields of related duties and functions. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

Service ratings identify subdivisions or specialties within a general rating. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

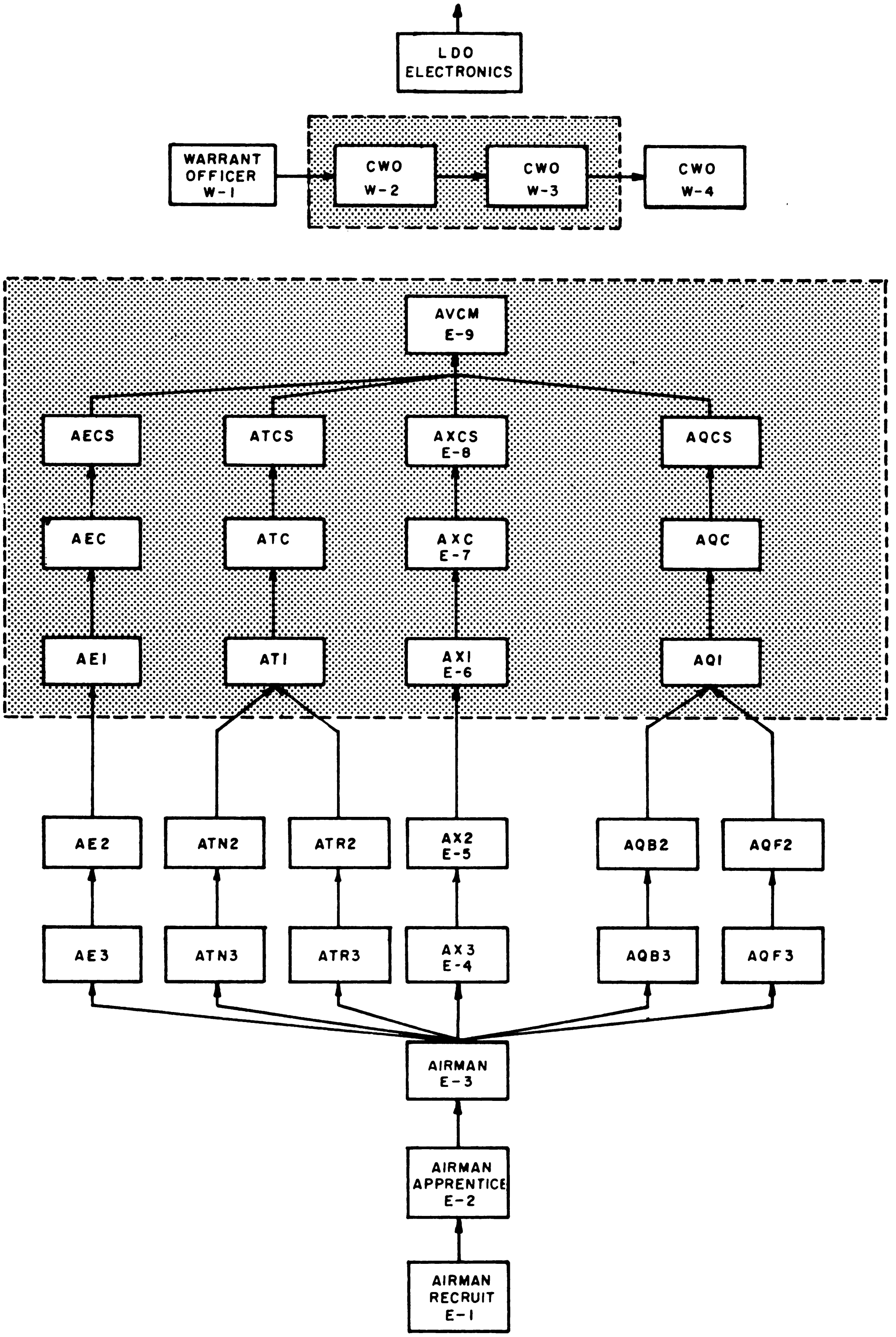
AVIATION ELECTRONICS TECHNICIAN RATING

The Aviation Electronics Technician rating, at pay grades E-4 and E-5, comprises the two service ratings ATN and ATR. At pay grades E-6 through E-8, there is a single general rating, AT. At pay grade E-9 the Aviation Electronics Technician rating loses its identify; personnel of pay grade E-8 in this rating, along with AECS, AQCS, and AXCS, advance to Master Chief Avionics Technician, AVCM. Figure 1-1 illustrates all paths of advancement for an Airman Recruit to Master Chief Avionics Technician (AVCM), Chief Warrant Officer (W-4), or to Limited Duty Officer (LDO). The advancement paths through the AT ratings are emphasized in the figure. Shaded areas indicate career stages where qualified enlisted men may advance to Warrant Officer (W-1), or selected commissioned Warrant Officers may advance to Limited Duty Officer. Additional information concerning promotion to Warrant or Commissioned Officer is presented later in this chapter.

Aviation Electronics Technicians inspect and maintain aviation electronic equipment except ASW and fire control equipment, including the following: detection, reconnaissance, identification, communication, navigation, display, and special purpose equipment; target drone and pilotless aircraft equipment; and related equipment and test equipment; and operate airborne CIC equipment.

Aviation Electronics Technician N (Radio and Radio Navigation Equipment) inspect and maintain aviation electronic identification, radio communication, and radio navigation equipment including: radio transmitting, receiving, relaying, and direction finding equipment; radio and radar altimeters; electronic interrogating and transponding equipment; distance and time difference measuring equipment; and related equipment and test equipment.

Aviation Electronics Technicians R (Radar and Radar Navigation Equipment) inspect and



AE.1

Figure 1-1.–Paths of advancement.

maintain aviation radar and electronic identification equipment, including: radar; radar display and relay equipment; electronic interrogating and transponding equipment; and related equipment and test equipment.

As an Aviation Electronics Technician (N or R) Third Class or Second Class, your assignment possibilities cover a wide range of duties and responsibilities. Your specific duties will depend to a large extent upon the type of organization to which you are assigned. It is probable that you will be assigned to billets which are concerned with the maintenance of electronic and associated equipment within the responsibility of your service rating. As either an ATN or an ATR you may be assigned to any of the several types of aircraft maintenance activities.

In an aircraft squadron, your duties are concerned primarily with the avionics division of the maintenance department. You will work under the supervision of the avionics division chief on all routine maintenance functions and on minor repair of electronic and associated equipments. You will also perform such other duties as may be assigned to you by the avionics officer or his representative. In some squadrons you may be assigned in the capacity of plane captain.

In the aircraft maintenance department (AMD) of a naval air station, you may be assigned duties similar to those in a squadron. You may be assigned to a check crew or to a troubleshooting crew. You may be assigned to a shop for more detailed maintenance than is normally performed by the squadron level activity.

On aircraft carriers you may be assigned to a crew which aids in the incorporation of required changes and modifications in squadron aircraft or electronic equipment. You may be required to perform work involving shop tools and services. You may perform more extensive maintenance than that normally performed by the squadron.

One of the billets available to the ATN2 or ATR2 may be assignments as an instructor in a training activity. Instructor duty may be performed either as a shore duty or as a sea duty assignment. Shore duty instructor assignments in your rate and rating are normally to the Aviation Electronics Technician School at the Naval Air Technical Training Center, Millington, Tennessee. Fleet instructor billets are available at various FAETU (Fleet Airborne Electronics Training Unit) NAMTG (Naval Air Maintenance Training Group), and RCVW (Readiness Air Wing) activities.

FAETU courses are usually concerned with a specific equipment or procedure. NAMTG courses may involve specific procedures, specific equipment, or specific aircraft. RCVW courses are normally concerned with the training of personnel in the operation and maintenance of equipment in new or unfamiliar types of aircraft.

LEADERSHIP

Since you have been in pay grade E-3 or E-4 for some time, you realize that more leadership is required of the higher rates. Not only are you required to have superior knowledge, but you are also required to have the ability to handle personnel. This ability increases in importance as you advance through the various rates as a petty officer.

In General Order No. 21, the Secretary of the Navy outlined some of the most important aspects of naval leadership. By naval leadership is meant the art of accomplishing the Navy's mission through people. It is the sum of those qualities of intellect, of human understanding, and of moral character that enable a man to inspire and to manage a group of people successfully. Effective leadership, therefore, is based on personal example, good management practices, and moral responsibility. The term leadership includes all three of these elements.

The current Navy Leadership Program is designed to keep the spirit of General Order No. 21 ever before you. If the threefold objective is carried out effectively in every command, the program will make you a better leader of men in your present billet and in your future assignments. As you advance up the leadership ladder, more and more of your worth to the Navy will be judged on the basis of the amount of efficient work you obtain from your subordinates rather than how much of the actual work you do yourself.

For information on the practical application of leadership and supervision, study Military Requirements for Petty Officer 3 & 2, NavPers 10056-B.

ADVANCEMENT

Some of the rewards of advancement are easy to see. You get more pay. Your job assignments become more interesting and more challenging. You are regarded with greater respect by officers and enlisted personnel. You enjoy the satisfaction of getting ahead in your chosen Navy career.

The advantages of advancement are not yours alone. The Navy also profits. Highly trained personnel are essential to the functioning of the Navy. By advancement, you increase your value to the Navy in two ways: First, you become more valuable as a person who can train others and thus make far-reaching contributions to the entire Navy; and second, you become more valuable as a technical specialist in your own rating.

HOW TO QUALIFY FOR ADVANCEMENT

What must you do to qualify for advancement? The requirements may change from time to time, but usually you must:

1. Have a certain amount of time in your present grade.
2. Complete the required military and professional training manuals.
3. Demonstrate your ability to perform all the practical requirements for advancement by completing the Record of Practical Factors, NavPers 1414/1.
4. Be recommended by your commanding officer, after the petty officers and officers supervising your work have indicated that they consider you capable of performing the duties of the next higher rate.
5. Successfully complete the applicable military/leadership examination which is required prior to participating in the advancement (professional) examination.

Some of these general requirements may be modified in certain ways. Figure 1-2 gives a more detailed view of the requirements for advancement of active duty personnel; figure 1-3 gives this information for inactive duty personnel.

Remember that the requirements for advancement can change. Check with your educational services office to be sure that you know the most recent requirements.

Advancement is not automatic. After you have met all the requirements, you are eligible for advancement. You will actually be advanced only if you meet all the requirements (including making a high enough score on the written examination) and if quotas permit.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare for advancement? Advancement is not an overnight affair. One does not take the advancement examination and wake up in the morning in the next pay grade. There is a path or sequence of events which one must pursue. Certain things must be done or accomplished before one is admitted to the advancement in rate examination. To prepare for advancement, you will, need to be familiar with the "Quals" Manual, the Record of Practical Factors, NavPers 1414/1. Training Publications for Advancement, NavPers 10052 (Series), and applicable Rate Training Manuals. The following sections describe them and give you some practical suggestions on how to use them in studying and preparing for the advancement in rate examination.

"Quals" Manual

The Manual of Qualifications for Advancement, NavPers 18068 (Series), gives the minimum requirements for advancement. This manual is usually called the "Quals" Manual, and the qualifications themselves are often called "quals." The qualifications are of two general types: military requirements, and professional (or technical) qualifications.

Military requirements apply to all ratings rather than to any one particular rating. Military requirements for advancement to third class and second class petty officer rates deal with military conduct, naval organization, military justice, security, watch standing, and other subjects which are required of petty officers in all other ratings.

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *	E1 to E2	E2 to E3	#† E3 to E4	# E4 to E5	† E5 to E6	† E6 to E7	† E7 to E8	† E8 to E9
SERVICE	4 mos. service— or completion of recruit training.	6 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4.	24 mos. as E-5.	36 mos. as E-6. 8 years total enlisted service.	36 mos. as E-7. 8 of 11 years total service must be enlisted.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, DT3, PT3. AME 3, HM 3			Class B for AGC MUC, MNC.		
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 1414/1, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS**	Locally prepared tests.	See below.	Navy-wide examinations required for all PO advancements.				Navy-wide, selection board.	
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition).	
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center			Bureau of Naval Personnel		

* All advancements require commanding officer's recommendation.
† 1 year obligated service required for E-5 and E-6; 2 years for E-6, E-7, E-8 and E-9.
# Military leadership exam required for E-4 and E-5.
** For E-2 to E-3, NAVEXAMCEN exams or locally prepared tests may be used.

Figure 1-2.–Active duty advancement requirements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
TOTAL TIME IN GRADE	4 mos.	6 mos.	15 mos.	18 mos.	24 mos.	36 mos.	36 mos.	24 mos.
TOTAL TRAINING DUTY IN GRADE †	14 days	14 days	14 days	14 days	28 days	42 days	42 days	28 days
PERFORMANCE TESTS	▨	▨	Specified ratings must complete applicable performance tests before taking examination.					
DRILL PARTICIPATION	Satisfactory participation as a member of a drill unit.							
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)	Record of Practical Factors, NavPers 1414/1, must be completed for all advancements.							
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)	Completion of applicable course or courses must be entered in service record.							
EXAMINATION	Standard Exam	Standard Exam or Rating Training.	Standard Exam required for all PO Advancements.			Standard Exam, Selection Board. Also pass Mil. Leadership Exam for E-4 and E-5.		
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center			Bureau of Naval Personnel		

* Recommendation by commanding officer required for all advancements.

† Active duty periods may be substituted for training duty.

Figure 1-3.—Inactive duty advancement requirements.

Professional qualifications are technical or professional requirements that are directly related to the work of each rating.

Both the military requirements and the professional qualifications are divided into subject matter groups; then, within each subject matter group, they are divided into practical factors and knowledge factors. Practical factors are things you must be able to DO. Knowledge factors are things you must KNOW in order to perform the duties of your rate.

The qualifications for advancement and a bibliography of study materials are available in your educational services office. Study these qualifications and the military requirements carefully. The written examination for advancement will contain questions relating to the knowledge factors and the knowledge aspects of the practical factors of both the military requirements and the professional qualifications. If you are working for advancement to second class, remember that you may be examined on third class qualifications as well as on second class qualifications.

The "Quals" Manual is kept current by means of changes which occur from time to time. Never trust any set of "quals" until you have checked the change number against an up-to-date copy of the "Quals" Manual. Be sure you have the latest revision.

Record of Practical Factors

Before you can take the Navy-wide examination for advancement, there must be an entry in your service record to show that you have qualified in the practical factors of both the military requirements and the professional qualifications. A special form known as the Record of Practical Factors, NavPers 1414/1 is used to keep a record of your practical factor qualifications. The form lists all practical factors, both military and professional. As you demonstrate your ability to perform each practical factor, appropriate entries are made in the DATE and INITIALS columns.

Changes are made periodically to the Manual of Qualifications for Advancement and revised forms of NavPers 1414/1 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes. The Record of Practical Factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rate but which are not identified as minimum qualifications for advancement.

If you are transferred before you qualify in all practical factors, NavPers 1414/1 should be forwarded with your service record to your next duty station. You can save yourself a lot of trouble by making sure that this form is actually inserted in your service record before you are transferred. If the form is not in your service record, you may be required to start all over again and requalify in the practical factors which have already been checked off.

A second copy of the Record of Practical Factors should be made available to each man in pay grades E-2 through E-8 for his personal record and guidance.

NAVPERS 10052

Training Publications for Advancement, NavPers 10052 (Series), is a very important publication for anyone preparing for advancement. This bibliography lists required and recommended Rate Training Manuals and other reference material to be used by personnel working for advancement. NavPers 10052 is revised and issued once each year by the Bureau of Naval Personnel. Each revised edition is identified by a letter following the NavPers number. When using this publication, be sure that you have the most recent edition.

If extensive changes in qualifications occur between the annual revisions of NavPers 10052, a supplementary list of study material may be issued in the form of a BuPers Notice. When you are preparing for advancement, check to see whether changes have been made in the qualifications. If changes have been made, see if a BuPers Notice has been issued to supplement NavPers 10052.

The required and recommended references are listed by rate level in NavPers 10052. If you are working for advancement to third class, study the material that is listed for third class. If you are working for advancement to second class, study the material that is listed for second class. Remember that you are also responsible for the references listed at the third class level.

In using NavPers 10052, you will notice that some Rate Training Manuals are marked with an asterisk (*). Any manual marked in this way is MANDATORY–that is, it must be completed at the indicated rate level before you are eligible to take the Navy-wide examination for advancement. Each mandatory manual may be completed by passing the appropriate enlisted correspondence course that is based on the mandatory training manual; passing locally prepared tests based on the information given in the training manual, or in some cases, successfully completing an appropriate Class A school.

Do not overlook the section of NavPers 10052 which lists the required and recommended references relating to the military requirements for advancement. All personnel must complete the mandatory military requirements training manual for the appropriate rate level before they can be eligible to advance.

The references in NavPers 10052 which are recommended, but not mandatory, should also be studied carefully. All references listed in NavPers 10052 may be used as source material for the written examinations at the appropriate rate levels.

Rate Training Manuals

There are two general types of Rate Training Manuals. Rating manuals (such as this one) are prepared for most enlisted rates, giving information that is directly related to the professional qualifications. Basic manuals give information that applies to more than one rate and rating.

Rate Training Manuals are revised from time to time to keep them up to date technically. The revision of a Rate Training Manual is identified by a letter following the NavPers number. You can tell whether any particular copy of a Rate Training Manual is the latest edition by checking the NavPers number and the letter following this number in the most recent edition of List of Training Manuals and Correspondence Courses, NavPers 10061. (NavPers 10061 is actually a catalog that lists current training manuals and correspondence courses; you will find this catalog useful in planning your study program.)

Rate Training Manuals are designed to help you prepare for advancement. The following suggestions may help you to make the best use of this manual and other Navy training publications when you are preparing for advancement.

1. Study the military requirements and the professional qualifications for your rate before you study the training manual, and refer to the "quals" frequently as you study. Remember, you are studying the training manual in order to meet these "quals."

2. Set up a regular study plan. If possible, schedule your studying for a time of day when you will not have too many interruptions or distractions.

3. Before you begin to study any part of the training manual intensively, become familiar with the entire manual. Read the preface and the table of contents. Check through the index. Look at the appendixes. Thumb through the manual without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.

4. Look at the training manual in more detail, to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a clear picture of the scope and content of the manual. As you look through the manual in this way, ask yourself some questions: What do I need to learn about this? What do I already know about this? How is this information related to information given in other chapters? How is this information related to the qualifications for advancement?

5. When you have a general idea of what is in the training manual and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit–it may be a chapter, a section of a chapter, or a subsection. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

6. In studying any one unit–chapter, section or subsection–write down the questions that occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

7. As you study, relate the information in the training manual to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.

8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without referring to the training manual, write down the main ideas that you have learned from studying this unit. Do not quote the manual. If you cannot give these ideas in your own words, the chances are that you have not really mastered the information.

9. Use Enlisted Correspondence Courses whenever you can. The correspondence courses are based on Rate Training Manuals or on other appropriate texts. As mentioned before, completion of a mandatory Rate Training Manual can be accomplished by passing an Enlisted Correspondence Course based on the Rate Training Manual. You will probably find it helpful to take other correspondence courses, as well as those based on mandatory training manuals. Taking a correspondence course helps you to master the information given in the training manual, and also helps you see how much you have learned.

10. Think of your future as you study Rate Training Manuals. You are working for advancement to third class or second class right now, but someday you will be working toward higher rates. Anything extra that you can learn now will help you both now and later.

SOURCE OF INFORMATION

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the military requirements for advancement and the professional qualifications of your rating.

Some of the publications described in this manual are subject to change or revision from time to time–some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying canceled or obsolete information will not help you perform efficiently or to advance; it is likely to be a waste of time, and may even be seriously misleading.

CHAPTER 2

AIRCRAFT MAINTENANCE ORGANIZATION

In order to maintain increasingly complex aircraft in their prime operating condition various aircraft maintenance organizations and procedures have been employed throughout the Navy. Prior to and during World War II, it was a general practice for every operating activity to have its own maintenance spaces, equipment, and a complement of maintenance personnel to accomplish all maintenance except overhaul. Due to variance in workload between squadrons, some shops were idle at times and could have been used by maintenance personnel from other squadrons on the same station to accomplish their work.

A combining of talents, efforts, facilities, and equipments for the accomplishment of common tasks was indicated. Through the process of evolution, combining of naval aircraft maintenance personnel and consolidation of maintenance facilities were effected on a Navy-wide basis when the Naval Aircraft Maintenance Program (NAMP) was established.

NAVAL AIRCRAFT MAINTENANCE PROGRAM

The Naval Aircraft Maintenance Program was designed to insure maximum utilization of manpower, material, and equipment and establish standard maintenance procedures and organizations for the accomplishment of maintenance on naval aircraft and associated equipment. The adoption of standard organizations and procedures promotes a high degree of uniformity among all activities in the methods that are used to manage and utilize maintenance personnel, material, and facilities. It results in a decrease in time required to indoctrinate recently assigned personnel.

The improvement of aircraft readiness is of utmost importance; costly, complex weapons systems and spares demand maximum command attention to the repair of critical items to enable aircraft to be in a ready status. It is therefore mandatory that all maintenance personnel have a thorough knowledge of and abide by the established procedures.

LEVELS OF MAINTENANCE

The task of maintaining naval aircraft in an operationally ready condition ranges from a few minutes of squadron servicing to months of overhaul in a depot level maintenance activity. To more efficiently accomplish maintenance on military aircraft the present concept is to divide the maintenance functions into three distinct levels—depot, intermediate, and organizational. The determination of what maintenance will be performed at each level is governed primarily by the availability and distribution of maintenance equipment and facilities.

Each command and support agency is responsible for continually reviewing the distribution of equipment and facilities to insure that the amount of maintenance performed at the lowest levels is consistent with available skills and personnel.

Organizational Maintenance

Organizational maintenance is the type of work performed by the operating squadron or unit on a day-to-day basis in support of its own operations. Maintenance performed at this level includes (1) inspection, (2) servicing, (3) handling, (4) "on-aircraft" corrective maintenance, including removal and installation of parts and components, (5) complying with technical directives (when prescribed), and (6) the necessary recordkeeping and reports peculiar to organizational maintenance.

Organizational maintenance in an operating activity is performed by permanently assigned personnel who are not responsible for intermediate maintenance. Organizational maintenance at shore stations (on aircraft assigned to the station) normally is a function of the Operations Maintenance Division (OMD). The OMD also provides organizational maintenance and such other assistance to transiting aircraft as may be directed by higher authority.

Intermediate Maintenance

Intermediate maintenance is that type of work performed in centrally located facilities for the support of operating activities within a designated geographical area, at a particular base or station, or aboard aviation ships. This level of maintenance is assigned for performance to such units as Station or Ships Aircraft Intermediate Maintenance Departments (AIMD), Marine Headquarters and Maintenance Squadrons, etc. Typical of the work performed at this level is shop type repair and test work on aircraft components and equipment from the supported units. Technical assistance, when required, is furnished by personnel of the intermediate maintenance facility to the supported operating activities.

Intermediate maintenance activities are normally manned by a nucleus of permanently assigned personnel and certain designated intermediate maintenance personnel temporarily assigned from the on-board tenant squadrons. When these squadrons deploy from their home stations, their intermediate maintenance personnel accompany them, and are then temporarily assigned to the AIMD if afloat or at their new station.

Depot Maintenance

Depot maintenance is that type of work normally accomplished in an industrial type facility (Naval Air Rework Facilities or contractors' plants.) This level includes overhaul and major repair or modification of aircraft, components, and equipments. It also includes the manufacture of specified aeronautical parts to be stocked as spares and the manufacture of kits for the accomplishment of aircraft and equipment modification. Installation of these spare-parts kits may be done at this or a specific lower level of maintenance.

Navy Depot maintenance activities are manned primarily by civilians. However, some military personnel are usually assigned and assist with the intermediate and organizational type work necessarily connected with the depot facility.

It can be seen from the foregoing that the three aircraft maintenance levels or categories provide for an orderly separation of the various maintenance tasks. The bases for the separation are complexity of the task, equipment and space requirements, the skill level of assigned personnel, and the scope of support responsibility.

AIRCRAFT MAINTENANCE DEPARTMENT ORGANIZATION

The organization for Aircraft Maintenance Departments provide firm lines of authority from the maintenance officer to personnel accomplishing the work for which the department is responsible. The term "department" used in this training manual is used as a general term which applies fully to all maintenance activities having a department head. In cases of maintenance activities assigned as divisions to other departments, the next echelon (division) is used in place of department. Branches become sections, and sections become units.

Major segments of the department are called divisions. Divisions are subdivided into branches and branches are subdivided into sections if necessary. The aircraft maintenance officer manages the department and is responsible to the commanding officer for the accomplishment of the department's mission.

The Aircraft Maintenance Department supports naval operations by the upkeep of assigned and supported aircraft and associated support equipments to the level and depth of maintenance assigned. Specific functions include the following:

1. Periodic maintenance and routine inspection and servicing of aircraft, associated

support equipment, and aeronautical material and components including the necessary disassembly, cleaning, examination, repair, modification test, inspection, assembly, and preservation.

2. Special work in compliance with technical directives or local instructions.
3. Correction of discrepancies.
4. Assurance of high quality of all work.
5. Maintenance of records and technical publications.
6. Maintenance and custody of tools and other organizational equipment.
7. Training of assigned personnel.
8. Conduct maintenance and ground handling safety programs.

INTERMEDIATE LEVEL ACTIVITY

The primary purpose of intermediate level maintenance is to support and supplement the work of organizational maintenance activities. These functions are normally performed in centrally located areas for the support of operating aircraft on a shore station, aboard a ship, or within a designated area.

The responsibility for intermediate level maintenance is assigned to station aircraft maintenance departments ashore and aircraft intermediate maintenance departments afloat and encompasses the following:

1. Repair and test of aircraft components requiring shop facilities not available in a lower level maintenance activity.
2. Aircraft changes and modifications.
3. Reporting and keeping of records.

Figure 2-1 illustrates an intermediate level maintenance department afloat with their respective work center code numbers.

Figure 2-2 illustrates an intermediate level maintenance department (shore), including work center code numbers. As can be seen in the figure, the activity is composed of staff and production divisions.

Maintenance/Material Control Officer

The Maintenance Material Control Officer is directly responsible to the Maintenance Officer for the management of the overall productive effort of the department. His general responsibilities include but are not limited to the following:

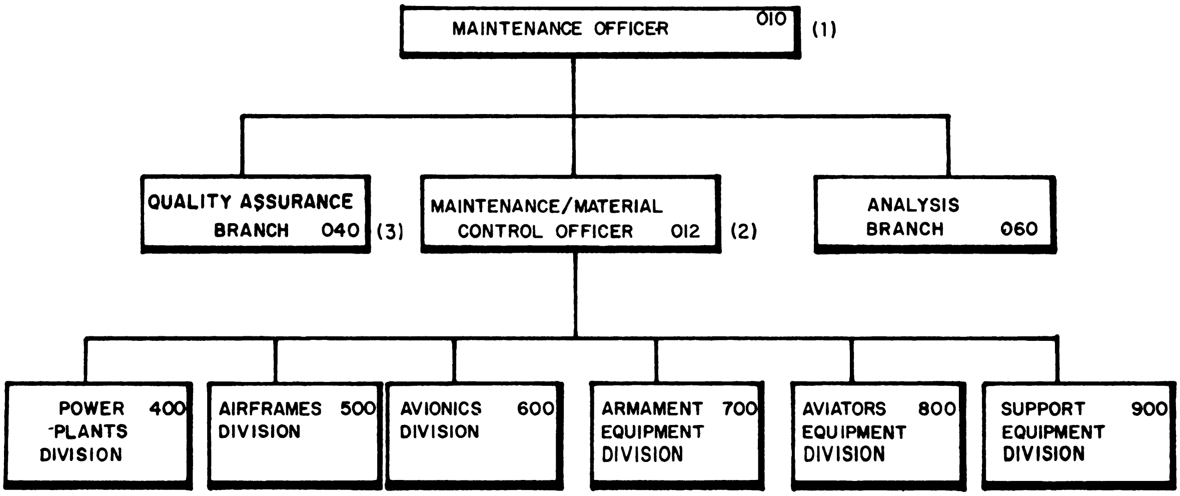
1. Scheduling, coordinating, and monitoring the workload of the department.
2. Maintaining liaison with supported/supporting activities and the local supply department to insure material requirements are fulfilled in order to keep productive capacity compatible with workload requirements.
3. Coordinating the order, receipt, and delivery of material, the administrative screening, scheduling, and control of processed components, and the control and usage of funds provided the department.

In discharging the duties of production control, the Maintenance/Material Control Officer will perform the following:

1. Plan and schedule the workload so as to insure maximum utilization of personnel, material, and resources.
2. Coordinate the actions of the production divisions to insure prompt movement of components through the department.
3. Assign production control numbers, work priorities, due-in and due out dates to the various work centers, and establish maintenance control procedures in order to effectively monitor the daily workload requirements.
4. Maintain technical directive control procedures for the department.
5. Review and approve work requests from supported activities.
6. Maintain files of completed maintenance action forms and work requests (6 months).
7. Maintain the Intermediate Maintenance Control Register.
8. Recommend and control cannibalization in accordance with applicable directives.
9. Submit reports as applicable.
10. Analyze daily and monthly maintenance data reports to ascertain effective utilization of personnel resources.

An assistant to the Maintenance/Material Control Officer will discharge the duties of material control by performing the following:

1. Plan, requisition, and expedite materials to enable the department to perform its mission quickly and effectively.
2. Pass all requirements for material for support of weapons system maintenance to the supporting SSC (Supply Support Center), and maintain a material control register for these items.


MAINTENANCE OFFICER 010
(1)
QUALITY ASSURANCE BRANCH 040
(3)
MAINTENANCE/MATERIAL CONTROL OFFICER 012
(2)
ANALYSIS BRANCH 060
POWER PLANTS DIVISION 400
AIRFRAMES DIVISION 500
AVIONICS DIVISION 600
ARMAMENT EQUIPMENT DIVISION 700
AVIATORS EQUIPMENT DIVISION 800
SUPPORT EQUIPMENT DIVISION 900

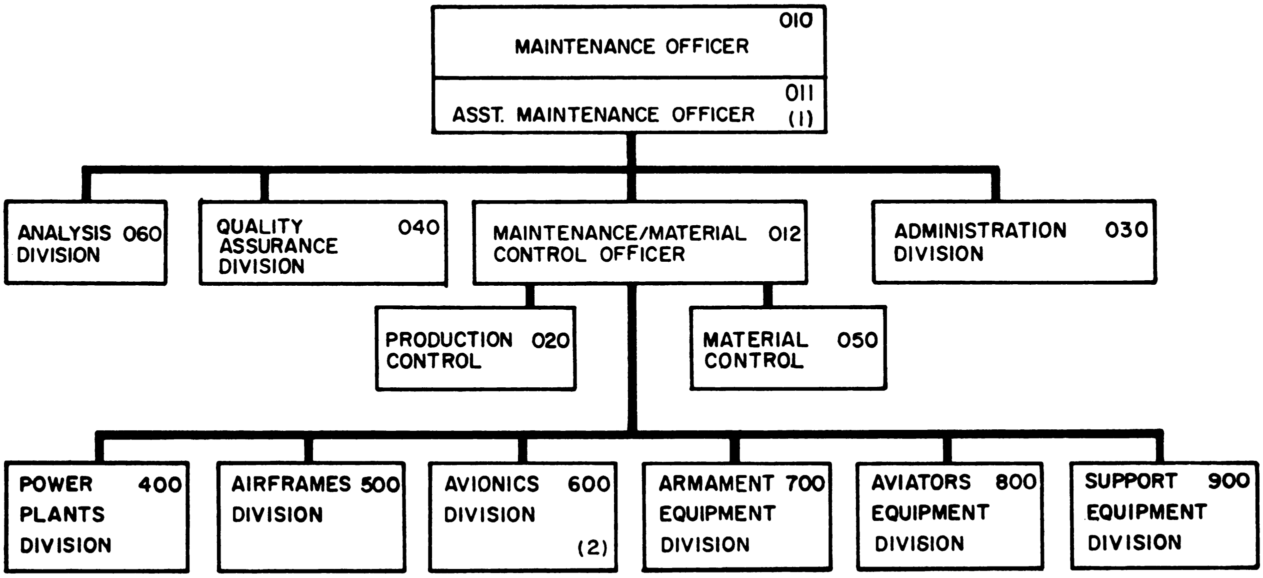
NOTES:

(1) AND (2) THE AIRCRAFT MAINTENANCE DEPARTMENT OFFICER (AFLOAT), DEPENDENT UPON HIS SENIORITY, WILL BE ASSIGNED AS EITHER THE INTERMEDIATE MAINTENANCE OFFICER OR MAINTENANCE/MATERIAL CONTROL OFFICER FOR CUSTODY/CONTINUITY PURPOSE UPON DEBARKATION OF THE AIR WING.

(3) BRANCH OFFICERS WILL BE TAD FROM AIR WING/GROUP TO THE IMA FOR MANAGEMENT RESPONSIBILITIES.

AT.1

Figure 2-1.–Intermediate level maintenance department organization, afloat.


MAINTENANCE OFFICER 010
ASST. MAINTENANCE OFFICER 011 (1)
ANALYSIS DIVISION 060
QUALITY ASSURANCE DIVISION 040
MAINTENANCE/MATERIAL CONTROL OFFICER 012
ADMINISTRATION DIVISION 030
PRODUCTION CONTROL 020
MATERIAL CONTROL 050
POWER PLANTS DIVISION 400
AIRFRAMES DIVISION 500
AVIONICS DIVISION 600
(2)
ARMAMENT EQUIPMENT DIVISION 700
AVIATORS EQUIPMENT DIVISION 800
SUPPORT EQUIPMENT DIVISION 900

NOTES: (1) WHEN ASSIGNED

(2) QUALIFICATION WILL BE PERFORMED BY THE TEST EQUIPMENT BRANCH OF THE AVIONICS DIVISION

Figure 2-2.–Intermediate maintenance department, shore.

AT.2

3. Establish delivery-pickup points for all material as mutually agreed upon by the Supply and Maintenance Officers. Insure that material received is expeditiously routed to the applicable work center.

4. Furnish technical advice and information to the supply activity on the identity and quantity of supplies, spare parts, and materials required for maintenance actions.

5. Establish procedures to insure the periodic inventory of tools and the adequate accountability of material and equipment.

6. Initiate surveys in the event of loss, damage, or destruction of accountable material.

7. Keep the Maintenance/Material Control Officer advised of the overall supply situation as it affects the department.

8. Verify Aircraft on Work Stoppage (AOWS) requisitions and prepare necessary reports in accordance with chapter IV of the 3-M Manual.

9. Perform cost and allotment record accounting, charting, and budgeting of costs applicable to the department.

10. Monitor the operation of toolrooms and maintain an updated IMRL (Individual Material Readiness List).

11. Arrange for return of prospective F condition of R/S material and locally repaired RFI material to supply.

12. Operate an administrative screening unit in accordance with chapter IV of the 3-M Manual.

13. Retain material within the department that is in AWP status until such time the requisition is filled and continually ascertain followup status on same.

Staff Division

Staff divisions are incorporated into the framework of aircraft maintenance activities for the purpose of providing services and support to the production divisions. A discussion of some of the more important functions of the staff divisions is contained in the following paragraphs:

ANALYSIS DIVISION.–The Analysis Division provides qualitative and quantitative analysis information to the Maintenance Officer in order to enable him to continually review the management practices within his organization by accomplishing the following functions:

1. Managing, coordinating, and monitoring the MDCS (Maintenance Data Collection System) for the department.

2. Reviewing MDR (Maintenance Data Reports) to discover and point out workload inequities, personnel inequities, and resource inequities.

3. Collecting, reviewing, and delivering source documents to data services for processing. Picking up complete data reports and disseminating throughout the organization.

4. Maintaining an adequate supply of manuals, source documents, registers, etc., on hand to insure continuity in the MDCS.

5. Developing an analytical plan which encompasses all maintenance functions to provide periodic audits of work center performance.

6. Developing charts, graphs, and displays for command presentations.

7. Maintaining an updated master roster for the department.

8. Coordinating and insuring that 3-M training services are provided to assigned personnel.

ADMINISTRATION DIVISION.–The standard organization structure for intermediate maintenance activities provides an administration division. (In activities where organizational is the highest level of maintenance performed, the organization structure does not provide for a separate administration division. In such activities the functions of the administration division are the responsibility of the Assistant Aircraft Maintenance Officer.)

Administration division personnel accomplish the following specific functions:

1. Establish and control a central reporting and record keeping system for all maintenance reports and correspondence.

2. Implement all directives concerning distribution, retention, and disposition of records and reports.

3. Provide clerical and administrative services for the department.

4. Reproduce as necessary and distribute incoming messages and other data.

5. Supervise and coordinate department administrative responsibilities with other departments/divisions as required.

6. Conduct liason with the Activity's Administration Department regarding department personnel matters.

7. Safeguard and distribute personal mail to department personnel, when appropriate.

8. Make proper distribution of all nontechnical information and publications.

9. Distribute approved locally issued maintenance instructions, reports, and studies.

10. Control classified material (excluding technical manuals and letter type directives) required by the department.

11. Establish and coordinate the department training requirements. Obtain necessary school quotas to support these requirements.

12. Determine requirements for and insure establishment of proper transportation and communication systems to provide complete support of the workload.

13. Assign spaces to the various divisions and establish the responsibility for security and cleanliness of such spaces.

14. Assume responsibility for the cleanliness and security of vacant or unassigned aircraft maintenance spaces.

15. Arrange department participation in joint inspections of facilities assigned to tenant activities especially incident to the departure of a tenant activity.

QUALITY ASSURANCE DIVISION.–The Quality assurance division provides the department head with the quality status of work accomplished, points up areas that need particular attention, and develops more realistic inspection requirements. Primary functions performed by this division are as follows:

1. Review all incoming technical publications and directives affecting the department to determine their application to quality assurance.

2. Prepare or assist in the preparation of maintenance instructions to insure that proper direction and emphasis is given to implementing quality assurance.

3. Maintain the master technical library for the department, including letter type technical directives and control classified technical publications for the department. Insure that each division/branch receives all publications applicable to its work areas and that these are kept current and complete. Where applicable, maintain the Reader-Printer and associated equipment for aircraft models supported.

4. Establish qualification requirements for Quality Assurance Representatives and Collateral Duty Inspectors. Review the qualifications of personnel nominated for these positions and endorse nominations to the Commanding Officer via the department head. Maintain a current record of all designated inspectors. Periodically promulgate a list of all designated inspectors by TIMI or command notice.

5. Obtain and utilize appropriate inspection equipment such as lights, mirrors, magnifying glasses, dye penetrant kits, pressure gages, etc. Insure that productive personnel have such equipment available and in use.

6. Periodically accompany Collateral Duty Inspectors on assigned inspections and recheck their qualifications.

7. Insure all work guides, checkoff lists, checksheets, maintenance requirement cards, etc., used to define or control maintenance operations are completed and current prior to issuing to crews/individuals.

8. Review all UR entries, explanations and descriptions to insure they are accurate, clear, concise and comprehensive prior to mailing. Additionally, the technician preparing the UR and either the Quality Assurance or Maintenance Officer must sign the completed UR.

9. Cause to be inspected all equipment received for use, returned for repair, or held awaiting repair to insure its material condition, identification, packaging, preservation, and configuration are satisfactory and, when applicable, that shelf life limits are not exceeded.

10. Perform inspections of maintenance equipment and precision measuring equipment to insure compliance with calibration and safety instructions.

11. Perform technical inspections of all maintenance equipment and facilities.

12. Provide for the continuous on-the-job training of all inspectors in the techniques and procedures pertaining to the conduct of inspections.

13. When directed or required, provide technical task forces to study trouble areas and submit recommendations for corrective action.

14. Maintain adequate records and data on discrepancies to enable establishment of trends

with the specific objective of determining when discrepancies in any area are ascending.

15. Maintain liaison with contractor, NAESU, NavAirSysComRep's, and other available field technical services. Establish and maintain liaison with other maintenance activities and rework points in order to obtain information on ways for improving maintenance techniques, quality of workmanship and quality assurance procedures.

16. Review maintenance data reports and note unnecessary and/or recurring discrepancies requiring special action.

17. Insure that established standard procedures are observed by production personnel when conducting bench checks, tests, and repairs of components including engines. Periodically check the performance of this work to insure the desired quality level is obtained.

18. Insure the configuration of aircraft components and support equipment is such that all essential/applicable modifications have been incorporated. This necessitates the review of appropriate records.

Production Divisions (Intermediate Level)

Maintenance of naval aircraft involves the actual performance of maintenance tasks by ordnancemen, mechanics, and technicians. The production divisions are manned by such personnel. Although each production division is broken down into work centers, which, on an organizational chart, are shown as the lowest element, this is not in keeping with their importance. If it were not for the production divisions and work centers, there would be no reason for the existence of any other part of the organization.

Intermediate maintenance level production divisions, such as are in AIMD's, are generally manned by personnel of the same rating. In organizational maintenance activities, some divisions are made up of personnel from several ratings. The type of work usually performed by an individual is the same regardless of the maintenance level at which he is working; ie., AD's work on engines, AQ's work on fire control equipment, ordnancemen work on armament equipment, etc. The difference between the work performed in production elements at various levels lies in the depth of maintenance performed.

The standard organization framework for intermediate level maintenance activities provides for six production divisions. (See fig. 2-1 or fig.2-2). The production divisions provide intermediate level maintenance on aircraft components and equipment for the supported activities. Some of the more important responsibilities and functions of these divisions are described in the following paragraphs.

POWERPLANTS.–The powerplants division is manned by Aviation Machinist's Mates who perform maintenance on powerplants, powerplant components, and associated systems.

AIRFRAMES.–Aviation Structural Mechanics are assigned to work centers in the airframes division. This division is responsible for the specified level of maintenance of the airframe and structural components; movable structures and surface including their hydraulic and pneumatic control and actuating systems and mechanisms; air-conditioning, pressurization, visual improvement, oxygen, and other utility systems; and seat and canopy ejection systems and components.

AVIONICS.–The avionics division is manned with the necessary combination of the following ratings of avionics equipment for the supported activities.

The Aviation Electrician's Mates maintain aircraft electrical and instrument systems.

The Aviation Electronics Technicians maintain and test aviation electronic equipment including detection, reconnaissance, identification, communication, navigation, display, and special purpose equipment.

The Aviation Antisubmarine Warfare Technicians maintain and test aircraft antisubmarine warfare (ASW) systems and equipment, including those related to magnetic anomaly detection, long and short-range underwater detection, nuclei detection, integrated displays, and associated ASW equipments.

Aviation Fire Control Technicians maintain and test aircraft armament control systems, including fire control, and bomb director systems.

AVIATORS' EQUIPMENT.–Aircrew Survival Equipmentmen are assigned to the aviators' equipment division. This division is responsible for intermediate level maintenance as required in connection with parachutes, liferafts, lifevests, pressure suits, oxygen masks, emergency equipment kits, flight clothing, oxygen regulators, automatic parachute actuators, aviators' protective helmets, etc. AME's may also be assigned to this division for the upkeep and support of the oxygen system, pressurization and air-conditioning systems, and other emergency equipment as assigned within the scope of that rating.

ARMAMENT EQUIPMENT.–Aviation Ordnancemen are assigned to the armament equipment division and are responsible for the maintenance of aircraft armament equipment and aviation ordnance equipment.

SUPPORT EQUIPMENT.–The Aircraft Support Equipment Technician (AS) performs the necessary maintenance on the support equipment assigned to the maintenance department and supported activities. Support equipment includes, but it not limited to, such items as test stands, workstands, mobile electric powerplants, pneumatic and hydraulic servicing equipment.

ORGANIZATIONAL LEVEL ACTIVITY

The responsibility for organizational level maintenance is assigned to operating units on a day-to-day basis–to support their own operations. Maintenance performed at this level includes aircraft servicing, aircraft inspections, minor adjustments, removal and replacement of defective parts and components, limited aircraft changes and modifications, recordkeeping, and reports. Figure 2-3 illustrates an organizational level maintenance department, including work center code numbers.

Maintenance/Material Control Officer

The Maintenance/Material Control Officer performs the following functions:

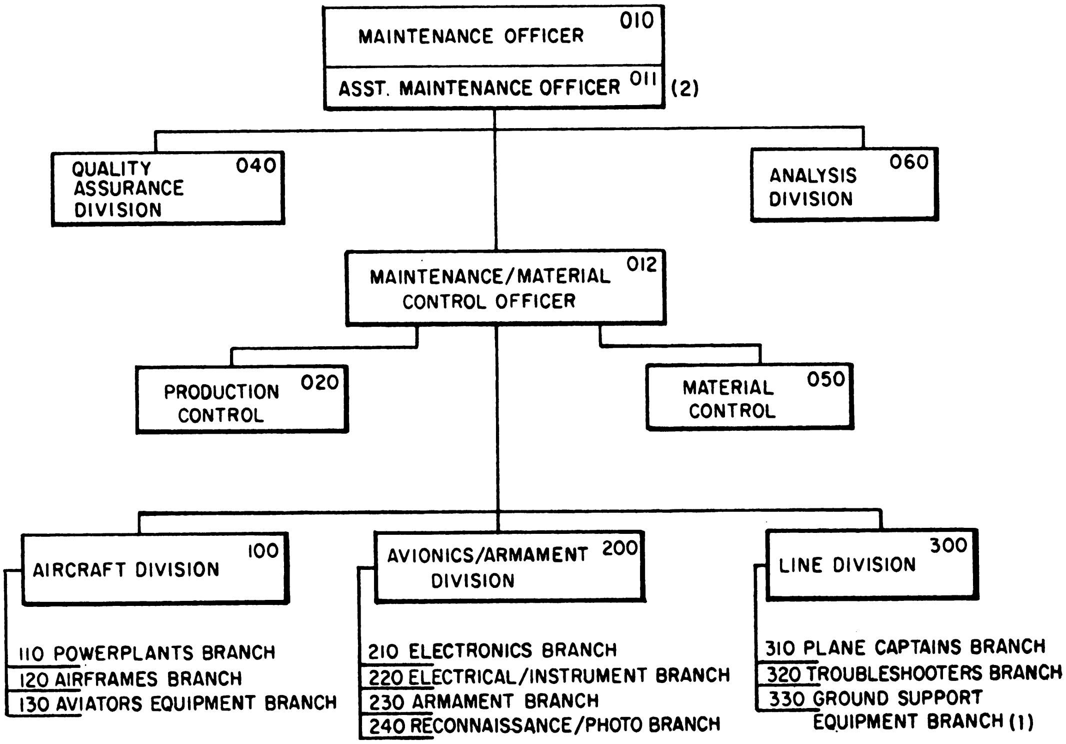
1. Scheduling, coordinating, and monitoring the workload of the department.
2. Maintaining liaison with the supporting activities and the local supply department to insure material requirements are fulfilled in order to keep productive capacity compatible with workload requirements.
3. Coordinating the ordering, receipt, and delivery of material, the administrative screening, scheduling, and control of processed components, and the control and usage of funds provided the department.

In discharging the duties of production control the Maintenance/Material Control Officer will:

1. Plan and schedule the workload so as to insure maximum utilization of personnel, material, and resources.
2. Assign job control numbers for each reported discrepancy.
3. Maintain the organizational maintenance control register (3 months).
4. Maintain an up-to-date status board.
5. Provide the Operations Department with required aircraft status and configuration information.
6. Maintain technical directive control procedures.
7. Relay discrepancies to work centers with complete information as to status, by the fastest method (i.e., telephone, intercommunications, etc).
8. Review and approve work requests to the supporting activity. (Maintain completed files.)
9. Recommend and control cannibalization in accordance with applicable directives.
10. Submit reports as required.
11. Receive certain completed source documents from work centers and:
    a. Update aircraft and equipment logs, accessory record cards, configuration forms, and associated documents.
    b. Forward complete forms to data analysis.
12. Receive complete source documents from data analysis after processing and file for historical records.
13. Conduct monthly maintenance meetings and publish a monthly maintenance plan.
14. Schedule all periodic and special inspections and insure maintenance test flights are conducted in accordance with applicable instructions.

In discharging the duties of material control, he will perform those applicable functions specified previously under intermediate level maintenance as well as the following:

1. Prepare documents for material required for operational support of weapon sys-


MAINTENANCE OFFICER 010
ASST. MAINTENANCE OFFICER 011 (2)
QUALITY ASSURANCE DIVISION 040
ANALYSIS DIVISION 060
MAINTENANCE/MATERIAL CONTROL OFFICER 012
PRODUCTION CONTROL 020
MATERIAL CONTROL 050
AIRCRAFT DIVISION 100
AVIONICS/ARMAMENT DIVISION 200
LINE DIVISION 300
110 POWERPLANTS BRANCH
120 AIRFRAMES BRANCH
130 AVIATORS EQUIPMENT BRANCH
210 ELECTRONICS BRANCH
220 ELECTRICAL/INSTRUMENT BRANCH
230 ARMAMENT BRANCH
240 RECONNAISSANCE/PHOTO BRANCH
310 PLANE CAPTAINS BRANCH
320 TROUBLESHOOTERS BRANCH
330 GROUND SUPPORT EQUIPMENT BRANCH (1)

NOTE:

(1) When responsibilities relative to operation and maintenance of ground support equipment are extensive, the Commanding Officer will establish a Ground Support Equipment Branch under the Line Division to coordinate and/or carryout organizational maintenance functions on assigned support equipment.

(2) When assigned.

AT.3

Figure 2-3.–Organizational maintenance department.

tems (i.e., material chargeable to BRAVO funds such as fuel, oil, and flight clothing, etc.) and material carried in SERVMART/JETMART outlets.

2. Verify NORSAIR (Not Operationally Ready Supply Aviation Item Report) requisitions and maintain (by BUNO) current NORSAIR status records.

3. Inventory aircraft upon receipt and transfer. Insure inventory logs entries are updated, authenticated and corrected.

Staff Divisions

The organizational level activity has only two staff divisions, having no administration division as explained under the intermediate level. The analysis division is the same for both activities; therefore, it is not discussed here. The Quality Assurance Division is the same as discussed for the intermediate level with the following additions:

1. Review "yellow sheets", maintenance data reports, periodic inspection records and note unnecessary and/or recurring discrepancies that may require special action.

2. Insure that standard established practices are observed for conducting ground tests, preflight, postflight, and daily inspections. Periodically accompany check crews, plane captains, or pilots during inspection (minimum, once a quarter).

3. Insure that pilots/crew are briefed prior to each test flight so that purpose and objectives are clearly understood.

4. Maintain current the Type Commander Maintenance Index Record.

Production Divisions

The organizational level activity provides three production divisions, which are subdivided into branches. Each of these branches/divisions performs many maintenance tasks in order for the operating unit to accomplish its assigned mission.

AIRCRAFT DIVISION.–The Aircraft Division is responsible for the accomplishment of the following functions:

1. Supervise, coordinate, and complete periodic maintenance and inspections. (Check crew leaders and such other personnel authorized by the Maintenance Officer will be permanently assigned.) Additional personnel required to perform periodic maintenance and inspections will be made available as required from other production divisions. The Maintenance/Material Control Officer is responsible for insuring that divisions assign qualified personnel for the completion of scheduled maintenance and inspections.

2. As directed by the Maintenance Officer and in conjunction with other production divisions, perform those applicable organizational maintenance functions in those areas relative to assigned branches; i.e., Airframes, Power Plants and Aviators Equipment.

3. Continuously advise the Maintenance/Material Control Officer of the status of work in progress.

4. Insure cleanliness of hangar and assigned spaces.

5. Nominate personnel for assignment as collateral duty inspectors.

6. Initiate requests for maintenance material.

7. Assume custody for tools and support equipment assigned to the Aircraft Division.

8. Interpret applicable directives and prepare, in draft form, maintenance instructions to implement such directives.

9. Recommend changes in techniques to promote maximum ground safety, safety of flight, and operational readiness of aircraft.

10. Carry out an active program for FOD (foreign object damage) control, as established by the Line Division Officer.

11. Initiate requests to maintenance/material control for job control numbers.

12. Provide troubleshooters and aircrew members, as required, and exercise technical supervision over such personnel.

13. Expedite the accomplishment of assigned work through the continuous evaluation of methods and procedures, and incorporate new techniques as appropriate.

AVIONICS/ARMAMENT DIVISION.–The Avionics/Armament Division is responsible for the accomplishment of the following functions:

1. Assign personnel required to accomplish scheduled periodic maintenance and inspections of assigned aircraft. (The Aircraft Division is responsible for the supervision, coordination, and completion of periodic maintenance and inspections.)

2. As directed by the Maintenance Officer and in conjunction with other production divisions, perform those applicable organizational maintenance functions in those areas relative to assigned branches, i.e., Electronics, Electrical/Instrument, Armament, and Reconnaissance/Photographic.

3. Continuously advise the Maintenance/Material Control Officer of the status of work in progress.

4. Insure cleanliness of assigned spaces.

5. Assume custody and accountability for assigned tools and support equipment.

6. Initiate requests for maintenance material.

7. Nominate qualified individuals for assignment as collateral duty inspectors.

8. Interpret applicable directives and prepare, in draft form, maintenance instructions to implement such directives.

9. Recommend changes in methods and techniques to promote maximum ground safety, safety of flight, and operational readiness of aircraft.

10. Initiate requests to maintenance/material control for job control numbers.

11. Provide troubleshooters and aircrew members, as required, and exercise technical supervision over such personnel.

12. Expedite the accomplishment of assigned work by continuous evaluation of methods

procedures and incorporate new techniques as appropriate.

LINE DIVISION.–The Line Division is responsible for the accomplishment of the following functions:

1. Assign personnel, as required, to accomplish periodic maintenance and inspections of assigned aircraft. (The Aircraft Division is responsible for the supervision, coordination, and completion of periodic maintenance and inspections.)
2. As directed by the Maintenance Officer and in conjunction with other production divisions, perform those applicable organizational maintenance functions in those areas relative to assigned branches; i.e., plane captains, troubleshooters, and ground support equipment (when established).
3. Coordination and direction of troubleshooters. Although troubleshooters will normally be assigned from other division on a daily basis, the Maintenance Officer may assign personnel permanently to a Troubleshooter Branch of the Line Division. A troubleshooter should accomplish correction of minor discrepancies.
4. Initiate requests to maintenance/material for job control numbers.
5. Provide to pilots/aircrews records of aircraft discrepancies and corrective actions for the preceding 10 flights of the aircraft.
6. Administer the plane captain program.
7. Nominate qualified personnel as collateral duty inspectors.
8. Participate in an active FOD (foreign object damage) prevention program.
9. Initiate requests for maintenance material.
10. Insure the cleanliness of assigned aircraft and spaces.
11. Assume custody and accountability for tools and aircraft maintenance support equipment assigned to the division/branch.
12. Insure the security and proper ground handling of aircraft and associated support equipment.
13. Recommend changes in methods and techniques to promote maximum ground safety, safety of flight, and operational readiness of assigned aircraft and associated support equipment.

NAVY MAINTENANCE AND MATERIAL MANAGEMENT (3-M) SYSTEM

The 3-M system is a program to insure the highest state of aircraft readiness and reliability at the lowest cost in men, money, and material. In accomplishing this, it must insure that maintenance personnel, equipment, and facilities are utilized to the fullest extent in the performance of maintenance and not wasted in other functions not requiring highly trained maintenance skills nor specialized and expensive maintenance equipment and facilities.

All aircraft weapon systems must be maintained to the maximum extent possible to perform 100 percent of the functions for which they were designed and to accomplish the assigned mission. Anything short of this goal is considered a compromise to readiness which cannot be afforded.

By analyzing maintenance costs and devising techniques to reduce cost wherever and whenever possible, many procedures and unnecessary actions can be minimized or eliminated entirely. Therefore, by doing away with the unnecessary, effort can be concentrated on increased readiness. The 3-M system embraces two broad areas–a Planned Maintenance System, and a Maintenance Data Collection System.

PLANNED MAINTENANCE SYSTEM

The Planned Maintenance System (PMS) is a system of maintenance planning and control that provides for the uniform accomplishment of planned preventive, rather than corrective, maintenance in all aircraft squadrons. A set of Maintenance Requirement Cards (MRC's) is provided for each type of aircraft, based on information in the Periodic Maintenance Requirements Manual (PMRM). The MRC's tell what inspections are to be performed, when and how they are to be performed, the skills, tools and equipment needed, the safety precautions to be observed, and the inspection sequence.

Many separate but interrelated functions and tasks combine to make up the maintenance workload that is required for support of modern aircraft. The times allocated and available for the accomplishment of this maintenance does not allow for all of these tasks to be considered, planned, and performed on an individual basis; therefore, it is necessary that they be combined, sequenced, and phased in the proper order if the overall task is to be accomplished in the most efficient manner. The best possible use of allocated time, manpower, materials, and funds is mandatory if the maximum potential weapons system availability and utilization are to be realized.

Operating aircraft are subject to a variety of stresses, strains, vibrations, and environments. If not inspected regularly for all defects, the aircraft would soon become inoperable. The correcting of discrepancies and timely lubrication are performed in conjunction with inspections and enable the aircraft to be flown safely until the next inspection.

The most frequent types of inspections which are performed by activities responsible for the maintenance of naval aircraft are described in the following paragraphs.

Daily Inspection

Daily inspections are accomplished between the last flight of the day and the next scheduled flight, if no more than 72 hours elapse between the inspection and the next scheduled flight. If more than 72 hours elapse between the inspection and the next flight, the inspection must be repeated. This inspection is basically a combination of requirements for checking equipment that requires a daily verification of satisfactory functioning, plus requirements that prescribe searching for and correction of relatively minor problems to prevent their progress to a state that would require major work to remedy. Other items which require inspection at intervals more frequent than prescribed for calendar inspections are also included on the daily inspection and are accomplished along with the daily inspection on the day they become due.

Preflight Inspection

A preflight inspection is performed prior to each flight. This inspection consists of checking the aircraft for flight readiness by performing visual examinations and operational tests to discover defects and maladjustments that, if not corrected, would cause accidents or aborted missions. It also includes a check to determine that the aircraft has been properly serviced for the next flight.

Postflight Inspection

A postflight inspection is performed on aircraft at the termination of the flight. This inspection includes the following:

1. Inspecting critical areas of the aircraft for obvious damage.
2. Servicing the aircraft with fuel, oil, oxygen, etc., to help maintain the aircraft in a ready-for-flight condition.
3. Installing of safety devices such as ejection seats and canopy safety pins, landing gear safety pins, and jury struts to maintain the aircraft in a safe condition.
4. Securing the aircraft after the last flight of the day. This includes installing all protective covers and plugs such as intake and exhaust covers, refrigeration and pressurization plugs, pitot covers, static vent plugs, etc.

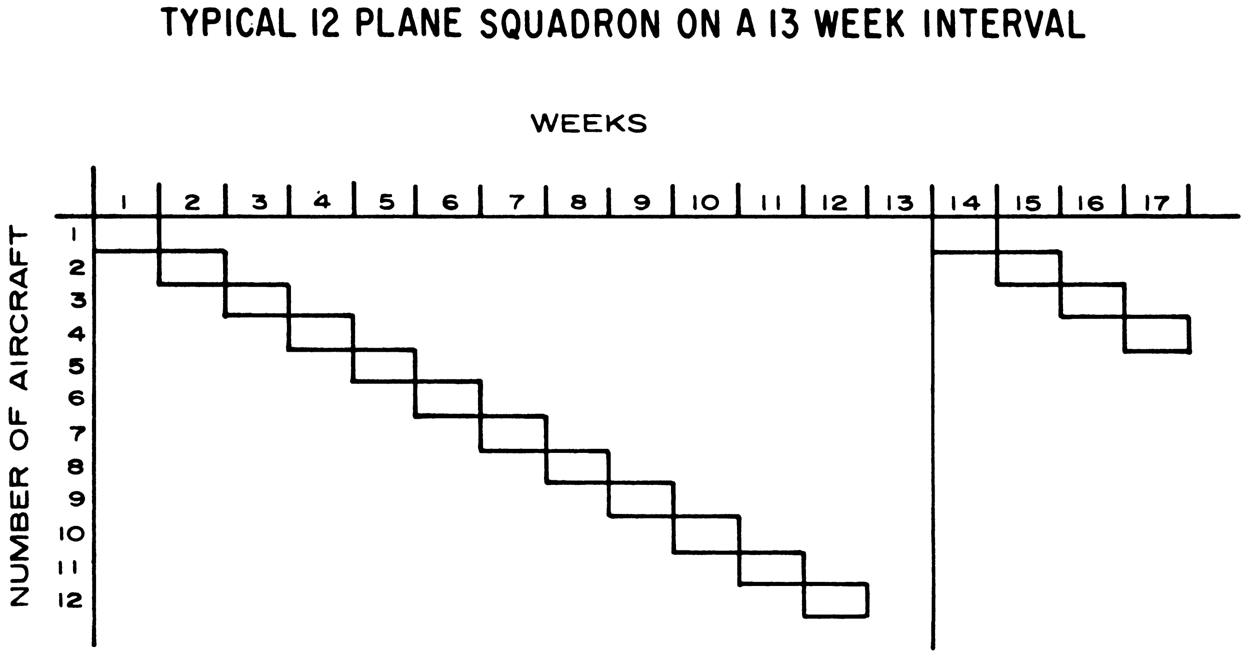
NOTE: This inspection is no longer accomplished except where locally authorized to satisfy specific requirements.

Calendar Inspection

The calendar inspection is a thorough and searching inspection of the aircraft. It consists of visual and operational checks of sufficient depth to uncover discrepancies or progressive deterioration within the aircraft that could affect safety of mission accomplishment. This type of inspection is divided into two categories–an ODD calendar and an EVEN calendar inspection–and consists of basic requirements plus additional items scheduled for compliance at less frequent intervals.

Most of the items to be inspected at less frequent intervals are divided evenly so that approximately half of the items are checked on the first (ODD) calendar inspection and the remainder are checked at the second (EVEN) inspection. Subsequent inspections repeat the same ODD–EVEN cycle.

Under this system, the appropriate inspection is conducted at the expiration of a specified number of calendar weeks. Figure 2-4 illustrates a squadron inspection interval.



AT.4

Figure 2-4.—Squadron inspection interval.

The Calendar Inspection System is an efficient system from a maintenance management standpoint. When aircraft are inspected under this system, the workload planning operation is simplified and the schedule maintenance in process is automatically stabilized.

The first inspection interval subsequent to Navy acceptance of a new aircraft under this inspection system commences on the date or at the time of the acceptance test flight. The first calendar inspection is performed at the completion of this first interval with subsequent inspections performed in sequence as previously mentioned.

The first inspection interval subsequent to standard rework commences on the date entered in the Aircraft Logbook by the rework activity certifying accomplishment of the equivalent calendar inspection. The next calendar inspection due is performed at the completion of this first interval and subsequent inspections are in sequence.

During special rework, the rework activity accomplishes all inspections falling due while the aircraft is in custody of the rework activity. Calendar inspections subsequent to special rework, therefore, continue in sequence. All calendar inspections accomplished by rework are noted in the Aircraft Logbook and the Aeronautical Equipment Service Record.

Acceptance Inspection

A minimum acceptance inspection consists of an inventory of installed material and loose gear, configuration verification, functional test of appropriate emergency systems, and a thorough daily inspection. Accepting activities may elect to increase the depth of inspection if the aircraft conditions warrant.

Conditional Inspection

A conditional inspection is an inspection which does not have a prescribed interval and depends upon certain circumstances or conditions (i.e., hard landings, engine overspeed/overtemp, one time inspections directed by higher authority but not issued as a technical directive).

Maintenance requirements for every model aircraft are promulgated by the Naval Air Systems Command. With every activity using the inspection criteria prescribed for their assigned aircraft models, it follows that any given aircraft model is subject to a standardized program of periodic maintenance wherever it is being operated.

Standardization of planned maintenance procedures is accomplished by use of a Periodic Maintenance Requirements Manual (PMRM), various sets of Maintenance Requirements Cards (MRC's), Sequence Control Charts, and related forms and reports. These publications and forms and their uses are described in the following sections.

PERIODIC MAINTENANCE REQUIREMENTS MANUAL

The Periodic Maintenance Requirements Manual contains all the planned periodic maintenance requirements for the applicable aircraft model for its entire anticipated service life. The maintenance requirements contained in the manual are set forth in a manner to specify the equipment to be inspected or examined and the condition to be sought in each case. Since defects that are discovered during inspections result in unplanned maintenance, and this maintenance cannot be accurately predicted or planned, this type of maintenance requirement is not included in the manual. Maintenance personnel must refer to the proper publications and directives for assembly, disassembly, check, test and repair procedures. The PMRM publication identification code is identical with the other manuals pertaining to the same aircraft model except for part 3. Aircraft manuals are described in chapter 4 of this manual.

Where conflict exists between the information contained in the PMRM and other maintenance directives, the manual–with one exception–takes precedence. This exception is the information given on any Maintenance Requirements Card with a later date than the latest change date given in the PMRM. Although the information given in both these directives should be identical, the cards can be and usually are, changed before the manual.

MAINTENANCE REQUIREMENTS CARDS (MRC'S)

The Maintenance Requirements Cards are the working documents for squadron inspections and preventive maintenance actions. These are 5 x 8 cards arranged by rating and work area to provide the most efficient sequence of accomplishment. Assembled into sets and numbered in sequence, the cards contain pertinent information required by each maintenance man to complete each task. Data for each task includes a description; the time required to perform the task; the power, tool, equipment, and material requirements; and detailed information on such items as adjustments, pressures, and torque values. Also, included, when necessary, is a diagram of the specific area of the aircraft in which the work is to be performed.

Individual sets of MRC's are parepared for preflight, postflight, daily, and calendar inspections. For aircraft models having odd and even calendar intervals, the calendar MRC set is further divided into three groups–calendar, odd calendar, and even calendar. The calendar group contains requirements that must be checked at every calendar inspection, while the other two groups are used alternately with the calendar MRC's. Therefore, at each calendar inspection, two, and only two, of the foregoing groups in the calendar set are used.

The work plan, or order of performing the requirements, specified on the Maintenance Requirements Cards is prearranged in two manners. The preflight, postflight, and daily work is performed item by item in sequential order arranged on consecutively numbered cards. The calendar inspection work is controlled by the order of arrangement of the items on the MRC's and, in addition, employs a sequence chart for scheduling of the MRC's. The calendar MRC's are not necessarily scheduled in numerical card number sequence.

NOTE: No part of any scheduled maintenance is certified (signed off) on the Maintenance Requirements Cards. Therefore, the MRC's may be used as many times as their condition permits.

SEQUENCE CONTROL CHARTS

Sequence Control Charts (SCC's) are used as a guide for the preparation of the actual calendar maintenance work schedule and as a means of controlling the assignment of work and personnel. These charts indicate what MRC's are to be complied with, the number and speciality of the personnel required, the times during which the separate jobs are scheduled to be performed, and the electric and hydraulic power conditions ("power on" or "power off") required during the work.

The SCC's are planned so as to effectively integrate all periodic maintenance work in a manner which will reduce the total out-of-service time required for the complete periodic maintenance job. The SCC's may consist of one, two, or three sheets, according to the requirements of the aircraft model. Generally, small aircraft not requiring engine removal during the calendar inspection will have only one chart containing both airframe and engine requirements to be accomplished on each calendar inspection. If engine removal is required for accomplishment of the calendar inspection, an engine SCC is provided for use by the shop performing the engine inspection.

Three charts are provided for aircraft models having inspection requirements divided between odd and even calendar intervals and requiring engine removal for inspection by shop personnel.

Calendar Sequence Control Charts have no application to the preflight, postflight, daily, or progressive aircraft rework requirements.

A plastic cover is placed over the chart when in use to facilitate marking of progress by the supervisor. The chart and the plastic cover are therefore reusable for as long as their condition warrants.

A portable workstand is used by the calendar maintenance supervisor to provide a local work control center for the accomplishment of calendar maintenance. This stand consists of four stowable legs, a deck tiedown assembly, a plastic chart holder, and a partitioned carrying case for MRC control and storage. A center storage section is provided for reference maintenance manuals. This stand, with the Sequence Control Charts, becomes the control center for the entire calendar inspection.

MAINTENANCE RECORD FORMS

Maintenance record forms are used to enable aircraft maintenance activities to schedule daily maintenance requirements, assign work in a preplanned manner, establish responsibility for work performed, record component replacement and discrepancies discovered, as well as the corrective action taken. The following sections describe the forms provided.

Daily Schedule Maintenance Planning Record

The Daily Schedule Maintenance Planning Record is used to plan and project the daily scheduled maintenance requirements for each individual aircraft between calendar periodic maintenance periods. It aids in assuring that required maintenance is scheduled on time and enables supervisory personnel to plan workloads accordingly. The form provides a number of spaces for each day in which to enter MRC numbers that require compliance on a basis other than every day (7 days, 14 days, conditional, etc.) It also provides a means for writing in all other scheduled maintenance due during the calendar maintenance period designated for the aircraft. This form is filled out to cover the calendar period. This is accomplished while the aircraft is undergoing calendar periodic maintenance so that all scheduled maintenance for the subsequent operating period is known at the time the aircraft is returned to an operational status.

Preflight/Daily/In-Flight Maintenance Record

This record form is used in conjunction with the Daily Schedule Maintenance Planning Record to enable scheduled work to be assigned in a preplanned manner between calendar inspections. This form controls and assigns responsibility for preflight, postflight, and daily scheduled maintenance including the special and conditional work that may be required. These forms can be prepared daily or made up in numbers sufficient to cover a desired period of time. Local conditions provide the best indication of the method to be employed.

INSPECTION PROCEDURES

Under the direction of the activity maintenance officer, Maintenance Control holds a planning conference several days in advance of the calendar inspection due date with representatives of Quality Assurance, Material Control, Production Divisions, designated calendar maintenance supervisor (CMS), and key members of the forthcoming calendar inspection team.

The purpose of the conference is to prepare the SCC by adding on any existing additional requirements. Representative items added on at this time are recent local or command maintenance items, discrepancies, component replacements, change incorporations, and other like items which either cannot be anticipated or cannot be programmed into all inspections on a fixed basis.

After the preinspection planning conference, the marked copy of the SCC is forwarded to quality assurance whose personnel certify that local inspection procedures are incorporated and that necessary MRC's, publications, and required maintenance personnel are available and alerted. The SCC is then forwarded to the CMS who prepares the forms required for the inspection.

To initiate the calendar inspection, the supervisor issues MRC's, in the sequence prescribed by the Sequence Control Chart, to personnel of each rating who make up the inspection crew. A single copy Maintenance Action Form (discussed later in this chapter) is issued to inspection crew personnel each time a segment of the card set is issued for accomplishment. When the inspection or servicing requirements specified on the cards are fulfilled, the Maintenance Action Form (MAF) is completed by the person accomplishing the work or his crew leader and returned with the MRC's to the supervisor. Figure 2-5 illustrates the cycle of paperwork for MAF's and MRC's from the supervisor to the worker and back again.

The supervisor marks the SCC to indicate which MRC's have been issued. Return of completed cards to the supervisor is also reflected on the chart. Even though the workstand provides a physical accounting, by separation, of the completed and uncompleted MRC's, the supervisor doublechecks the return of each MRC by noting it on the chart. A mark should exist on the chart for each completed card, each card not in possession of the supervisor, and each card that could not be completed due to NORS (not operational ready-supply.)

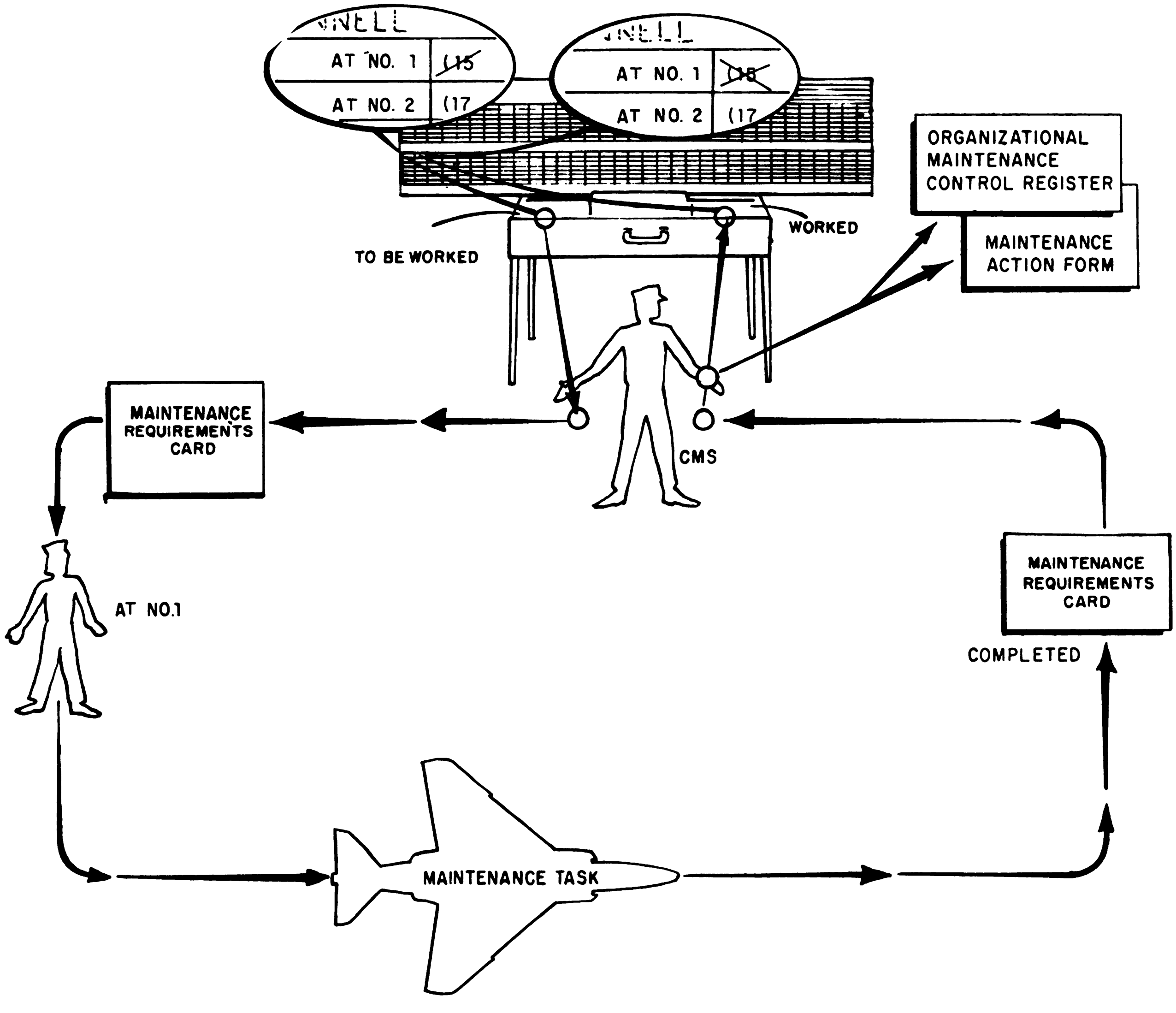
Accomplishment and completion of each issued MRC are the responsibility of the appropriate specialist of the inspection crew. Each card must be completed by the specialist and returned to the supervisor. Uncompleted MRC's are returned to the supervisor and the Maintenance Action Form must contain entries listing the number of cards and items completed, and a notation in detail of which items were not completed and why.

The control of the status and the scheduling of the calendar inspection are the responsibility of the supervisor. It is essential that all discrepancies that are discovered are cleared through him. The supervisor (CMS) notifies the appropriate work centers for the correction of discrepancies which cannot be corrected by the calendar maintenance crew.

A set of Preflight, Postlight, and Daily Maintenance Requirements Cards is maintained in the line shack for each aircraft assigned. Prior to each flight, those preflight, postflight, and daily checks, as required, are performed by the applicable personnel and signed off on the appropriate card.

The Preflight/Daily/In-Flight Maintenance Record (fig.2-6) should be filled in completely. Inasmuch as several inspections may be in progress at the same time, it becomes especially important that the BUNO and MODEX (or side number) spaces be accurately filled in. In some cases these records may be locally preprinted with the necessary basic information (applicable card number and rating), and the person performing the work need only complete the necessary spaces in longhand. Figure 2-6 illustrates this case.

Daily inspections are accomplished in the same manner as the preflight inspections. The accomplishment of the items on the daily inspection cards is also reported on the Preflight/Daily/In-Flight Maintenance Record. The daily inspection card sets contain the minimum daily, and conditional maintenance requirements for the applicable aircraft. Those card requirements that are to be performed on every daily inspection are titled "Daily." Those card requirements that are titled "Conditional" are



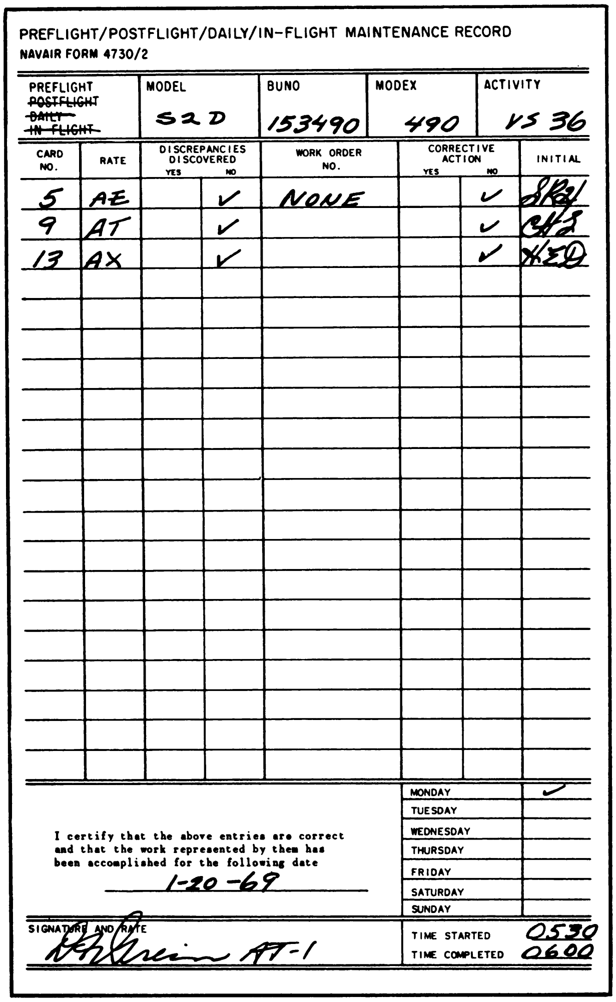
AT.5

Figure 2-5.—Normal MAF and MRC cycle.

items required on other than daily basis; for example, 72 hours, 7 days, 10 days, 30 days, etc. Whenever these special or conditional items are to be included in the daily inspection, the appropriate cards are issued to the persons concerned as part of the daily card set.

FORMS, RECORDS, AND REPORTS

In order that all commands and offices concerned with naval aviation be kept fully informed of the operational and maintenance experiences of naval aviation operating activities, a large variety of records must be maintained and many reports made. Some of the reports provide purely historical information, some furnish statistical data for analyzing efficiency and economy of maintenance and operation, and others have a bearing on the supply support furnished the activity. These records and reports are not limited to aircraft. Support equipment, manhours, and personnel training are representative of other areas of recordkeeping and reporting.



PREFLIGHT/POSTFLIGHT/DAILY/IN-FLIGHT MAINTENANCE RECORD
NAVAIR FORM 4730/2

PREFLIGHT ~~POSTFLIGHT~~ ~~DAILY~~ ~~IN-FLIGHT~~	MODEL	BUNO	MODEX	ACTIVITY
	S2D	153490	490	VS 36

CARD NO.	RATE	DISCREPANCIES DISCOVERED YES	DISCREPANCIES DISCOVERED NO	WORK ORDER NO.	CORRECTIVE ACTION YES	CORRECTIVE ACTION NO	INITIAL
5	AE		✓	NONE		✓	
9	AT		✓			✓	
13	AX		✓			✓	

I certify that the above entries are correct and that the work represented by them has been accomplished for the following date

1-20-69

MONDAY	✓
TUESDAY	
WEDNESDAY	
THURSDAY	
FRIDAY	
SATURDAY	
SUNDAY	

SIGNATURE AND RATE AT-1

TIME STARTED 0530
TIME COMPLETED 0600

AT.6

Figure 2-6.—Preflight/Daily/In-flight Maintenance Record.

Through analyses of the data provided, the commands and offices, for whose use the records and reports are submitted, are enabled to better control overall operations. Standardization of maintenance and material areas is improved, unsafe or uneconomical trends are spotted and corrected earlier, and through feedback information, the service experience of other similar activities is made available to all who would find it helpful.

For each record that has to be kept and for every report that has to be made a governing instruction has been issued. These instructions usually give detailed instructions for the preparation of the record or report, prescribe the form and frequency of submission, and indicate the office to which they are to be forwarded. For purely local records such as training records, local instructions are provided to guide the recordkeeping.

The remaining portion of this chapter is devoted to a discussion of a few of the records and reports which are of main concern to the technician.

MAINTENANCE INSTRUCTIONS

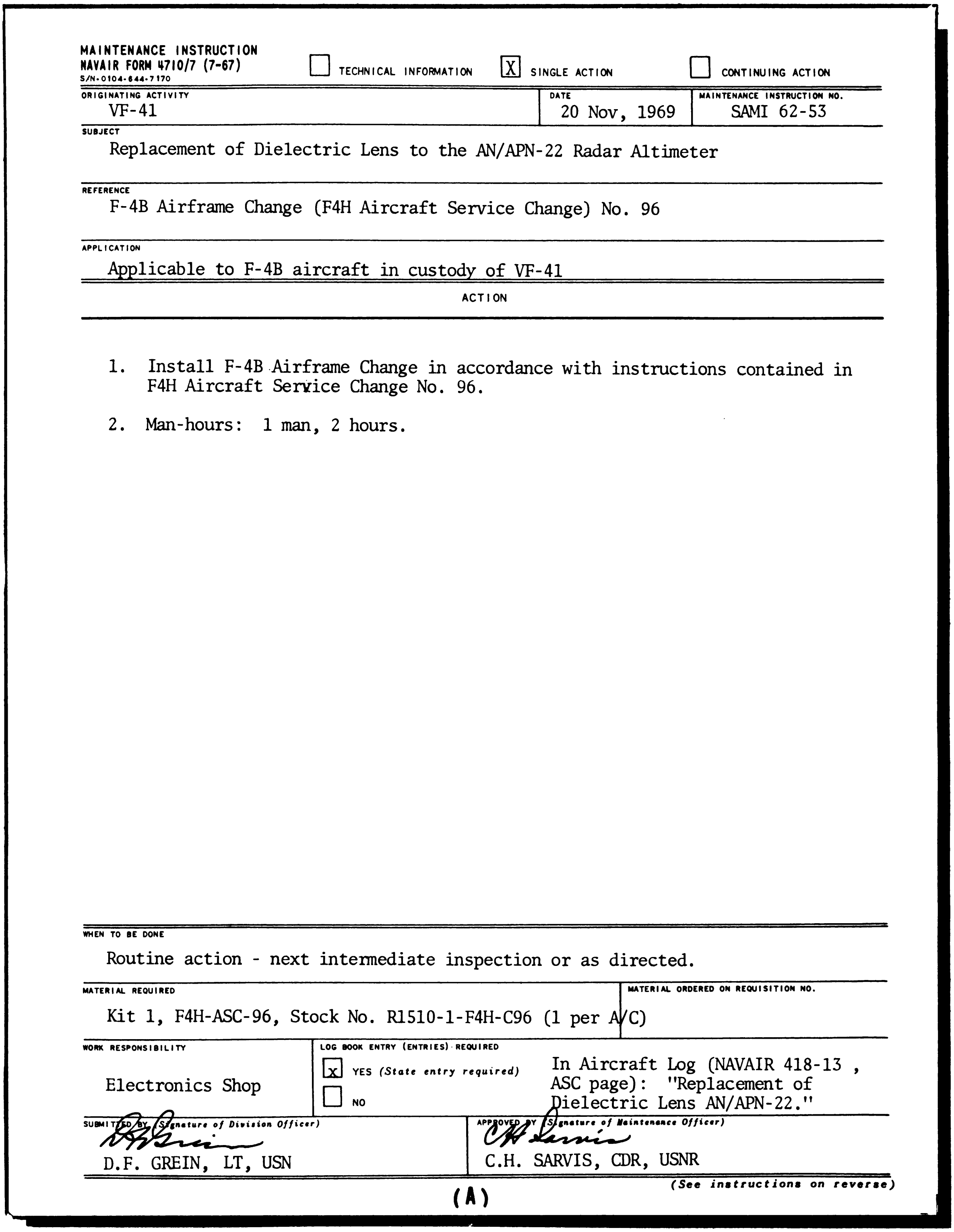
Certain basic forms and procedures are set forth in NavAir Instruction 4700.2 (Series) as guidelines for the standardization of maintenance practices. It is essential that each maintenance man become familiar with the purposes and applications of these forms.

When the occasion arises for the aircraft maintenance officer to pass technical information to the mechanics and technicians, a Maintenance Instruction (Form NavAir 4710/7) is issued. This instruction is used for interpreting, amplifying, or clarifying technical directives and maintenance directives received from higher authority. It is also used to promulgate local instructions as necessary.

The instruction is normally prepared by the cognizant division, but it may be prepared by any division designated by the maintenance officer. The rough draft should be reviewed by the quality assurance officer and by the maintenance/material control officer before being submitted to the aircraft maintenance officer for approval.

The Maintenance Instruction (fig.2-7) must be prepared carefully, since this is the instrument by which the division officer directs his men. Command directives received in the form of messages are often so brief that they require considerable amplification and background information in order to be understandable at the working level. On the other hand, directives received in letter form may have been prepared for all aviation activities, and may be excessively lengthy and detailed. Only parts of such directives may apply locally, so they need condensation and selection to adapt them to local conditions.

The same form is used to promulgate instruction of three types: (1) Single Action Main-



MAINTENANCE INSTRUCTION
NAVAIR FORM 4710/7 (7-67)
S/N-0104-644-7170

☐ TECHNICAL INFORMATION ☒ SINGLE ACTION ☐ CONTINUING ACTION

ORIGINATING ACTIVITY	DATE	MAINTENANCE INSTRUCTION NO.
VF-41	20 Nov, 1969	SAMI 62-53

SUBJECT
Replacement of Dielectric Lens to the AN/APN-22 Radar Altimeter

REFERENCE
F-4B Airframe Change (F4H Aircraft Service Change) No. 96

APPLICATION
Applicable to F-4B aircraft in custody of VF-41

ACTION

1. Install F-4B Airframe Change in accordance with instructions contained in F4H Aircraft Service Change No. 96.
2. Man-hours: 1 man, 2 hours.

WHEN TO BE DONE
Routine action - next intermediate inspection or as directed.

MATERIAL REQUIRED	MATERIAL ORDERED ON REQUISITION NO.
Kit 1, F4H-ASC-96, Stock No. R1510-1-F4H-C96 (1 per A/C)	

WORK RESPONSIBILITY	LOG BOOK ENTRY (ENTRIES) REQUIRED	
Electronics Shop	☒ YES *(State entry required)* ☐ NO	In Aircraft Log (NAVAIR 418-13 , ASC page): "Replacement of Dielectric Lens AN/APN-22."

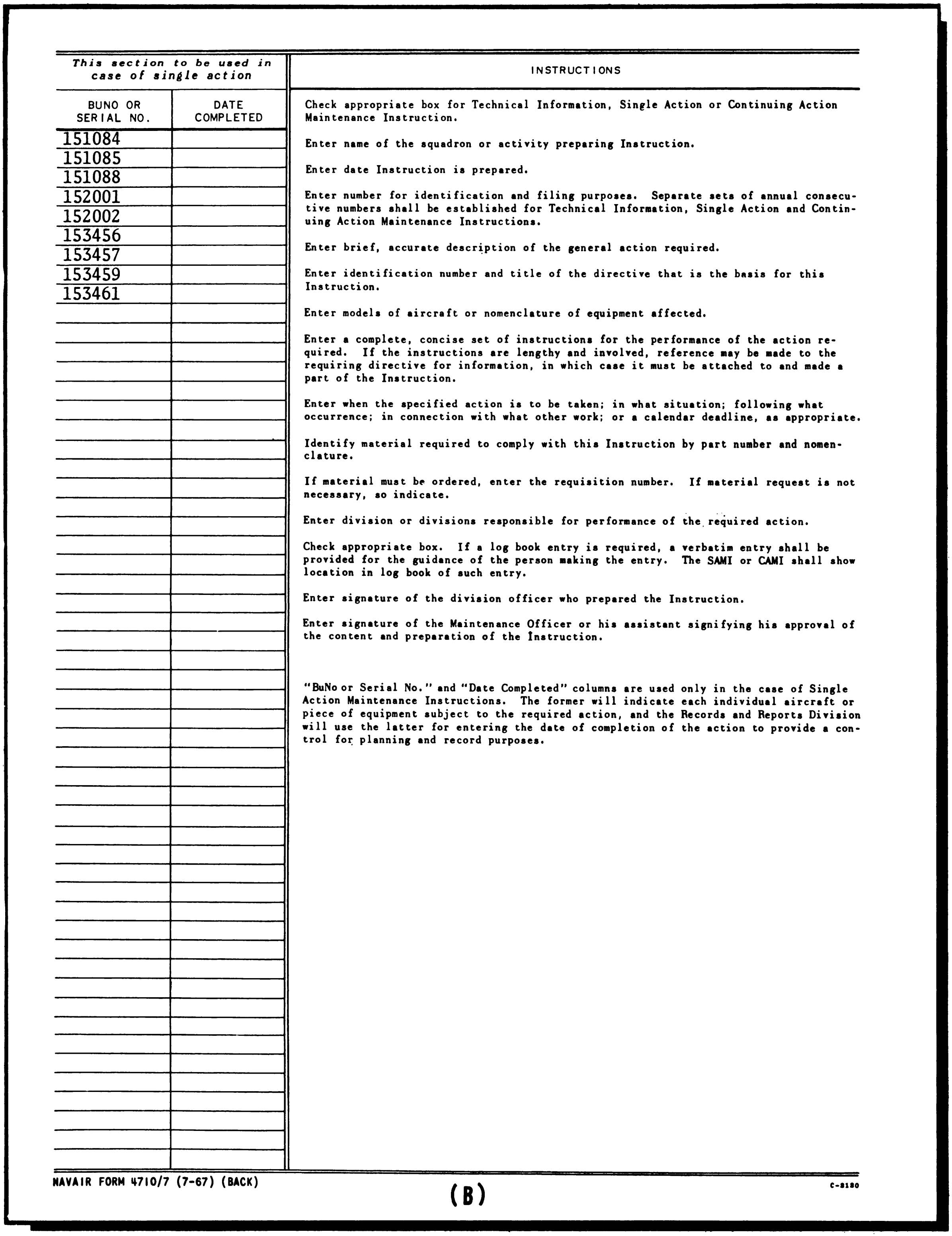
SUBMITTED BY *(Signature of Division Officer)*	APPROVED BY *(Signature of Maintenance Officer)*
D.F. GREIN, LT, USN	C.H. SARVIS, CDR, USNR

(See instructions on reverse)

(A)

AT.7

Figure 2-7.—Maintenance Instruction; Form NavAir 4710/7. (A) Front page.



This section to be used in case of single action	
BUNO OR SERIAL NO.	DATE COMPLETED
151084	
151085	
151088	
152001	
152002	
153456	
153457	
153459	
153461	

INSTRUCTIONS

Check appropriate box for Technical Information, Single Action or Continuing Action Maintenance Instruction.

Enter name of the squadron or activity preparing Instruction.

Enter date Instruction is prepared.

Enter number for identification and filing purposes. Separate sets of annual consecutive numbers shall be established for Technical Information, Single Action and Continuing Action Maintenance Instructions.

Enter brief, accurate description of the general action required.

Enter identification number and title of the directive that is the basis for this Instruction.

Enter models of aircraft or nomenclature of equipment affected.

Enter a complete, concise set of instructions for the performance of the action required. If the instructions are lengthy and involved, reference may be made to the requiring directive for information, in which case it must be attached to and made a part of the Instruction.

Enter when the specified action is to be taken; in what situation; following what occurrence; in connection with what other work; or a calendar deadline, as appropriate.

Identify material required to comply with this Instruction by part number and nomenclature.

If material must be ordered, enter the requisition number. If material request is not necessary, so indicate.

Enter division or divisions responsible for performance of the required action.

Check appropriate box. If a log book entry is required, a verbatim entry shall be provided for the guidance of the person making the entry. The SAMI or CAMI shall show location in log book of such entry.

Enter signature of the division officer who prepared the Instruction.

Enter signature of the Maintenance Officer or his assistant signifying his approval of the content and preparation of the Instruction.

"BuNo or Serial No." and "Date Completed" columns are used only in the case of Single Action Maintenance Instructions. The former will indicate each individual aircraft or piece of equipment subject to the required action, and the Records and Reports Division will use the latter for entering the date of completion of the action to provide a control for planning and record purposes.

NAVAIR FORM 4710/7 (7-67) (BACK)

(B)

C-8180

AT.8

Figure 2-7.—Maintenance Instruction; Form NavAir 4710/7. (B) Back Page.

tenance Instruction–SAMI, (2) Continuing Action Maintenance Instruction–CAMI, (3) Technical Information Maintenance Instruction–TIMI. A separate numbering sequence is set up for each type. This facilitates file control and serves as a cross-reference on work orders and inspection records. Each supporting work order merely carries the serial number of the Maintenance Instruction, rather than a repetition of the description of the work to be accomplished.

Single Action Maintenance Instruction

When work ordered is such that it will be completed on one aircraft or piece of equipment by carrying out the instructions set forth, and will not require further action at any time or in any situation on that aircraft or piece of equipment, it is properly the subject of a SAMI; for example, an Airframe Change on all bureau numbers of a certain model of aircraft.

Continuing Action Maintenance Instruction

A CAMI is issued when the work ordered may be required to be repeated at intervals on the same aircraft or piece of equipment due to elapsed time or as a result of the peculiarities of some particular piece of equipment.

Technical Information Maintenance Instruction

A TIMI may be prepared when a directive or situation dictates that technical information be promulgated within the activity. When it is necessary to disseminate information, such as techniques and local policy, which does not direct the accomplishment of specific work at defined intervals but which is sustaining in nature, a TIMI may properly be issued; for example, procedures and techniques for aircraft fueling.

WORK REQUEST

NavAir Form 4710/6 (fig.2-8) has been provided for use as a work request form. The work request is originated by a maintenance activity. The supporting activity reviews the request and either approves or disapproves. If the request is approved, a work order is issued and the requesting activity is notified when the work is completed. If the request is disapproved, the reason for disapproval is entered on the work request and it is returned to the originator. Detailed instructions for preparing the work request are printed on the back of the form.

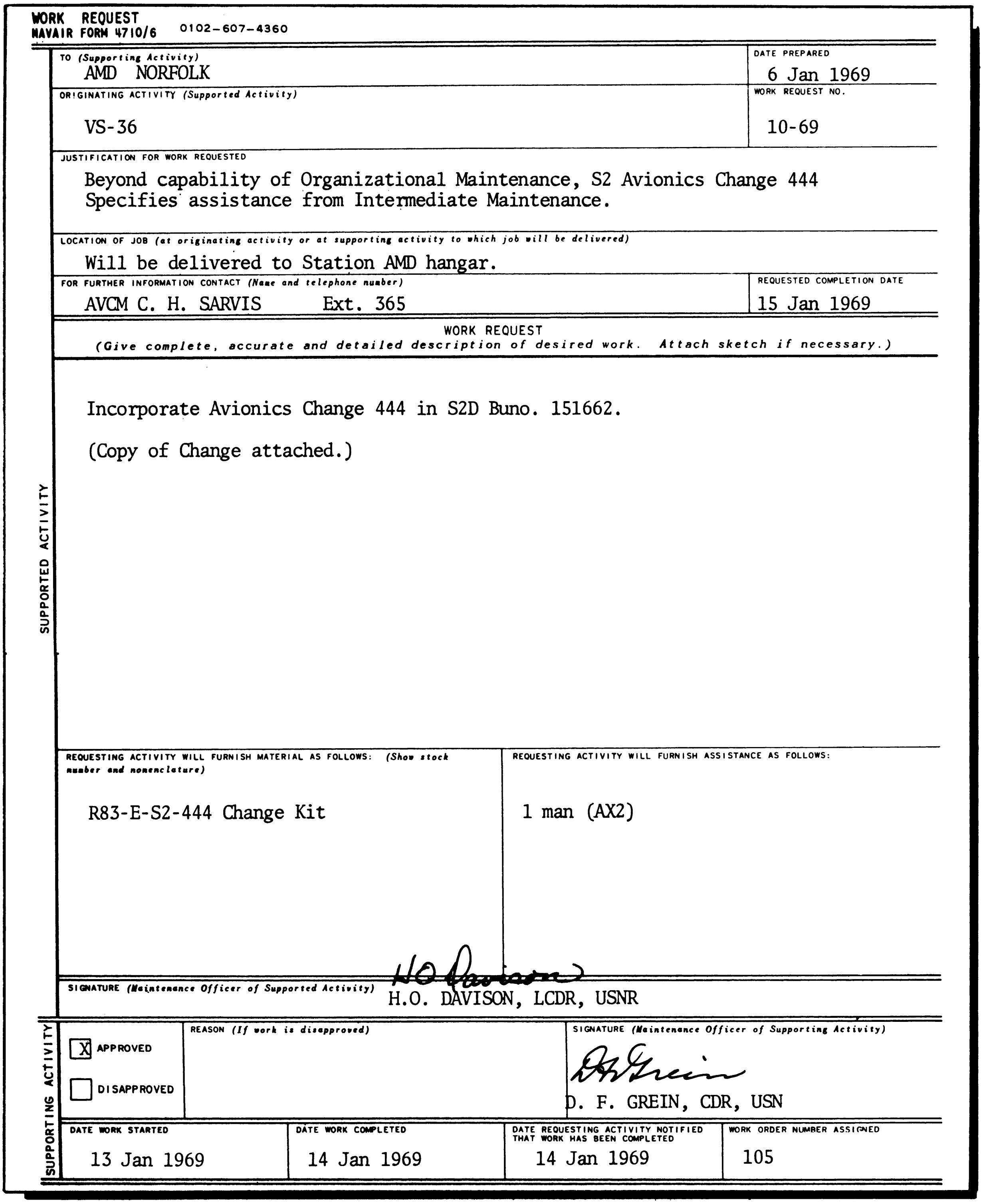
MAINTENANCE DATA COLLECTION FORMS

This section outlines the procedure for documenting maintenance actions and actions taken in support of maintenance. These actions consume manhours or material or both. Therefore, manhour accounting is also discussed as part of maintenance data collection. The forms used to record this maintenance data are known as source documents. These source documents furnish the input information for the Maintenance Data Collection System. Each source document provided is used for recording and reporting specific maintenance information and much of this information is recorded in code form. The selection of which form to use depends on the type of work to be accomplished.

The forms selected for discussion are listed as follows:

1. Maintenance Action Form (MAF)–used to record actual maintenance actions (work).
2. Support Action Form (SAF)–a record of tasks performed in support of maintenance.
3. Manhour Accounting Form–a record of manhours expended is essential if efficiency is to be maintained.
4. Technical Directives Compliance Form–used to record actions taken in compliance with technical directives.
5. Configuration Control Form–a record of the configuration of repairable items as a result of compliance with a technical directive.
6. Unsatisfactory Material/Condition Report (UR)–used to report specific information concerning material failure and/or defects and other special situations.

Of the six forms listed, the MAF, SAF, and Manhour Accounting Card are discussed in detail because of the frequency with which the worker comes into contact with them. The remaining forms are described only briefly.



WORK REQUEST
NAVAIR FORM 4710/6 0102-607-4360

SUPPORTED ACTIVITY

TO *(Supporting Activity)*: AMD NORFOLK

DATE PREPARED: 6 Jan 1969

ORIGINATING ACTIVITY *(Supported Activity)*: VS-36

WORK REQUEST NO.: 10-69

JUSTIFICATION FOR WORK REQUESTED: Beyond capability of Organizational Maintenance, S2 Avionics Change 444 Specifies assistance from Intermediate Maintenance.

LOCATION OF JOB *(at originating activity or at supporting activity to which job will be delivered)*: Will be delivered to Station AMD hangar.

FOR FURTHER INFORMATION CONTACT *(Name and telephone number)*: AVCM C. H. SARVIS Ext. 365

REQUESTED COMPLETION DATE: 15 Jan 1969

WORK REQUEST
(Give complete, accurate and detailed description of desired work. Attach sketch if necessary.)

Incorporate Avionics Change 444 in S2D Buno. 151662.

(Copy of Change attached.)

REQUESTING ACTIVITY WILL FURNISH MATERIAL AS FOLLOWS: *(Show stock number and nomenclature)*: R83-E-S2-444 Change Kit

REQUESTING ACTIVITY WILL FURNISH ASSISTANCE AS FOLLOWS: 1 man (AX2)

SIGNATURE *(Maintenance Officer of Supported Activity)*: H O Davison
H.O. DAVISON, LCDR, USNR

SUPPORTING ACTIVITY

☒ APPROVED
☐ DISAPPROVED

REASON *(If work is disapproved)*:

SIGNATURE *(Maintenance Officer of Supporting Activity)*:
D. F. GREIN, CDR, USN

DATE WORK STARTED	DATE WORK COMPLETED	DATE REQUESTING ACTIVITY NOTIFIED THAT WORK HAS BEEN COMPLETED	WORK ORDER NUMBER ASSIGNED
13 Jan 1969	14 Jan 1969	14 Jan 1969	105

AT.9

Figure 2-8.—Work Request, NavAir Form 4710/6

MAINTENANCE ACTION FORM (MAF)

There are two maintenance action forms, but the format of both is identical. (See fig. 2-9.) The difference is that one is a multiplecopy form and the other is a single copy form. Whether the worker uses the single copy or the multiple copy depends upon whether a repairable item is removed from the aircraft.

A single copy MAF (blue) is used to document the following actions:

1. Repair work on the equipment which does not involve removal of defective or suspected defective repairable components.
2. That portion of calendar, conditional, periodic, acceptance, and transfer inspections which involve the search for (not repair of) defects, sometimes called the "look phase."
3. Removal of components for check, test, inspect, and service actions.
4. Item removal and replacement for cannibalization.
5. Fix-in-place actions discovered during inspections.
6. Recording manhours accumulated during work stoppage for parts or maintenance.
7. Recording accumulated maintenance manhours at the end of a reporting period for a job not completed.
8. To report assistance from work centers in support of a basic work center.
9. In support of a repairable item processing through an Intermediate maintenance activity.

The multiple copy MAF is a set (original and three copies) which is used when processing a defective or suspected defective repairable component through the Intermediate maintenance activity. It is also used to induct a component (including engines) into an Intermediate maintenance activity for compliance with technical directives. However, the multicopy MAF is not used for the accomplishment of test, inspect, and service actions. Instead, see 9, under single copy MAF.

Each copy of the multicopy MAF is used as follows:

Copy 1 (white)–Used for removal/replacement of repairable components from aircraft, engines, or support equipment.

Copy 2 (yellow)–Used to provide status control and suspense information to the Component Control Section of the Supply Support Center for items undergoing processing in the Intermediate maintenance activity.

Copy 3 (green)–Used to document the action taken by the Intermediate maintenance activity on repairable components. Such actions include a determination that the part was beyond the capability of maintenance (BCM), repaired, checked O.K., etc.

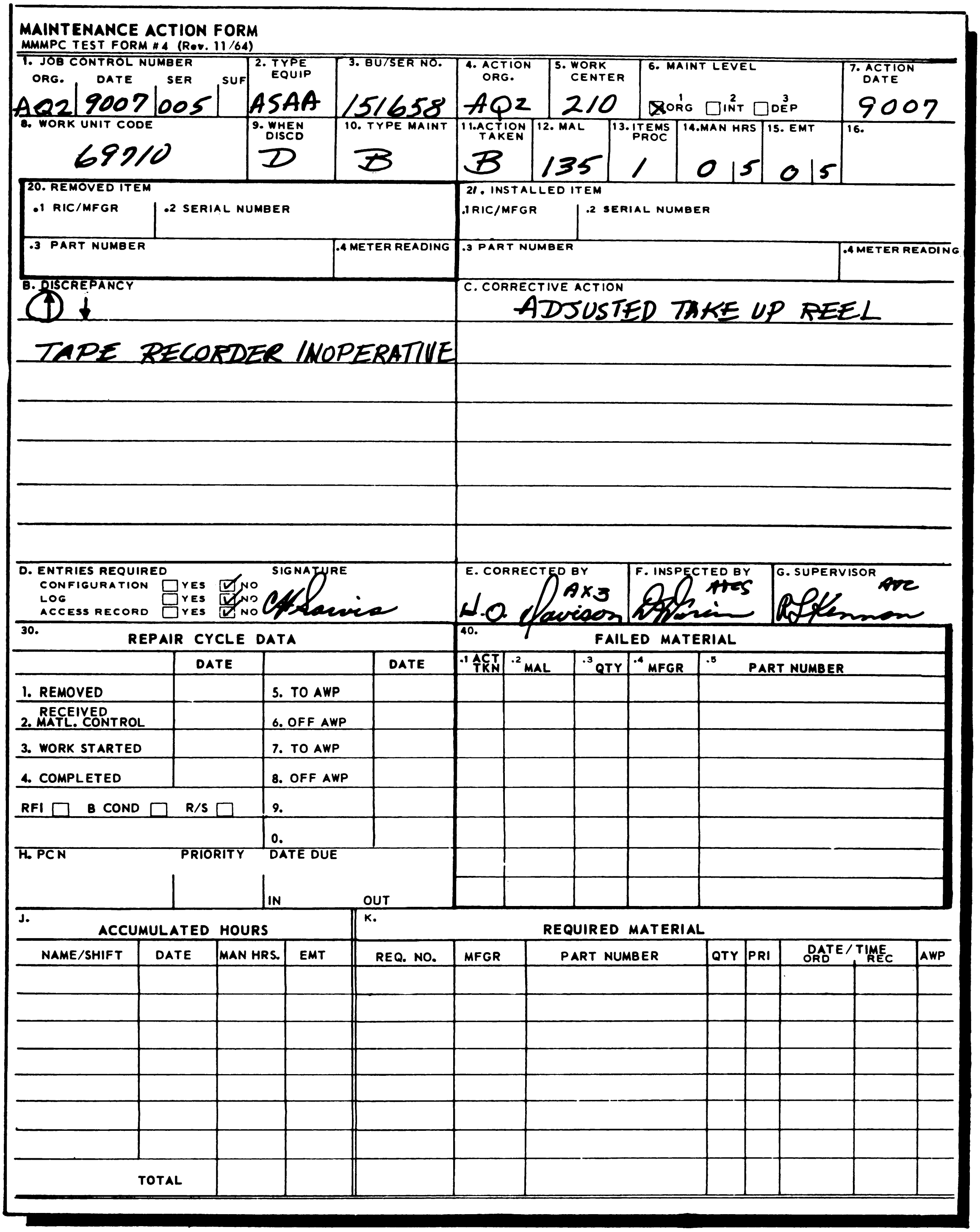
Copy 4 (hard back)–Used to provide status control to the component control section of the Supply Support Center and serves as an information copy for all off-station shipment of material requiring rework.

The maintenance action form is originated in the work center. When the work center supervisor is notified of required work, he enters this information in a work center register and assigns men to the job. Upon completion of the work the worker or crew leader fills out the MAF, using information from the supervisor's work center register and verifies completion of the work, manhours expended, materials used, etc. Referring to figure 2-9, completion of the numbered and lettered spaces is as described in the following paragraphs.

Job Control Number (JCN). The job control number is a 10- or 11-character "number" that serves as a base for maintenance data reporting and maintenance control procedures. The JCN provides separate identification of each maintenance action, when necessary. It also identifies the maintenance actions accomplished by Intermediate maintenance activities in support of organizations or an organizational discrepancy. The four parts of the JCN are organization code, date code, sequence number, and suffix and are thus explained.

The organization code is a 3-character code composed of letters and numerals (alphanumeric) which identifies an organization. This part of the JCN is published by higher authority for each individual activity performing or responsible for aircraft maintenance and always remains constant within the activity.

The date code identifies the date of which the JCN was initiated or assigned to a job. Therefore, this is not necessarily the date on which the work was actually started. NOTE: The date code, known as the Julian date, identifies the year and the numerical day of the year and consists of four numbers. The first number indi-



MAINTENANCE ACTION FORM
MMMPC TEST FORM #4 (Rev. 11/64)

1. JOB CONTROL NUMBER ORG. AQ2 · DATE 9007 · SER 005 · SUF	2. TYPE EQUIP ASAA	3. BU/SER NO. 151658	4. ACTION ORG. AQ2	5. WORK CENTER 210	6. MAINT LEVEL ☒ 1 ORG ☐ 2 INT ☐ 3 DEP	7. ACTION DATE 9007

8. WORK UNIT CODE 69710	9. WHEN DISCD D	10. TYPE MAINT B	11. ACTION TAKEN B	12. MAL 135	13. ITEMS PROC 1	14. MAN HRS 0 5	15. EMT 0 5	16.

20. REMOVED ITEM .1 RIC/MFGR	.2 SERIAL NUMBER		21. INSTALLED ITEM .1 RIC/MFGR	.2 SERIAL NUMBER	
.3 PART NUMBER		.4 METER READING	.3 PART NUMBER		.4 METER READING

B. DISCREPANCY

Ⓣ ↓

TAPE RECORDER INOPERATIVE

C. CORRECTIVE ACTION

ADJUSTED TAKE UP REEL

D. ENTRIES REQUIRED CONFIGURATION ☐ YES ☑ NO LOG ☐ YES ☑ NO ACCESS RECORD ☐ YES ☑ NO SIGNATURE	E. CORRECTED BY H. O. Davison AX3	F. INSPECTED BY ATCS	G. SUPERVISOR ATC

30. REPAIR CYCLE DATA

	DATE		DATE
1. REMOVED		5. TO AWP	
2. RECEIVED MATL. CONTROL		6. OFF AWP	
3. WORK STARTED		7. TO AWP	
4. COMPLETED		8. OFF AWP	
RFI ☐ B COND ☐ R/S ☐		9.	
		0.	

H. PCN	PRIORITY	DATE DUE IN	OUT

40. FAILED MATERIAL

.1 ACT TKN	.2 MAL	.3 QTY	.4 MFGR	.5 PART NUMBER

J. ACCUMULATED HOURS

NAME/SHIFT	DATE	MAN HRS.	EMT
TOTAL			

K. REQUIRED MATERIAL

REQ. NO.	MFGR	PART NUMBER	QTY	PRI	DATE/TIME ORD	DATE/TIME REC	AWP

AT.10

Figure 2-9.–Maintenance action form (MAF).

cates the last digit of the calendar year, the next three numbers specify the number of days in the calendar year which have elapsed since January 1 of that year; for example, the Julian date 8350 identifies the 350th day of 1968 or, in more familiar terms, 15 December 1968; 9006 is the 6th day of 1969 or January 6, 1969. All dates used in the maintenance data reporting program are reported in Julian dates since any date in any 10-year period can be shown in just four digits. Encoding the date in this manner simplifies recordkeeping the data reduction by machine methods.

The sequence number part of the JCN (identified SER on the form) is either a 3-digit number that runs consecutively from 001 to 999 or a 3-character alphanumeric code with an alphabetic first character and two numbers which run from 00 to 99. The sequence number is normally assigned in sequence as new jobs come up. When the number 999 (or alphanumerically, 99) has been assigned, the next number in sequence is again 001. The alphanumerical sequence numbers are used only when documenting calendar inspection maintenance actions.

The JCN suffix is a single alphabetic character which is added to the basic JCN (those parts just discussed) to identify a subcomponent repair job which was done separately from the major repair job. This code applies to Intermediate maintenance only. An example of this is when a defective item is replaced with a good one during the course of a major job. The MAF job control number used to process the removed part through repair (Intermediate) maintenance would be the same basic code as the major job but the suffix A would be added to identify the subcomponent repair.

Type Equipment. The type equipment code is a 4-character code consisting entirely of letters. The type equipment code on the MAF shown in figure 2-9 is the code for the S-2A aircraft. These codes are listed in official directives and are mandatory for use.

Bu/Ser No. A bureau number or serial number is a number that identifies a specific end item or component, including aircraft and their components. The number is usually assigned by the manufacturer (serial numbers) or the Navy (bureau numbers), and is used to differentiate between a given end item and others of the same type, model, series, design, etc.

Action Org. Entered here is the organization code number of the organization performing the work. In case the same organization that assigned the JCN is performing the work, the code entered is the same as the organization code in the JCN.

Work Center. Entered here is the work center code of the work center accomplishing the maintenance action described on the MAF. This is either (1) the code of the worker's assigned work center, or (2) if temporarily assigned, the code of the work center to which he is temporarily assigned.

Maintenance Level. Entered here is a checkmark in the block which describes the level of maintenance being performed. This information should not be confused with organizational assignment of personnel. For instance, a man assigned to an Intermediate maintenance activity may actually work on an aircraft. Such a job would normally be considered as Organizational level work. As a general rule, all work performed on aircraft or missiles is considered as Organizational level maintenance and work performed off the aircraft or missile as Intermediate level maintenance.

Action Date. Entered here is the Julian date on which (1) the action is completed, or (2) the MAF is turned in to account for manhours accumulated against a job, or (3) the job is turned over to another work center, or (4) a job is interrupted due to the fact that supply must go off station for parts, or (5) a reporting period ends.

Work Unit. The work unit code is usually a 5- or 7-character alphanumeric code which normally identifies the system, subsystem, component and part of the item being worked on. (The look phase of calendar inspections is documented on single copy MAF's by entering "030" in block 8, "0" in blocks 9 and 11, and "000" in block 12.) Work unit codes are published in Work Unit Code Manuals for end items in two major categories; Type/model/series for aircraft, drones, and missiles; and aircraft maintenance support equipment. Five-character work unit codes from these manuals are used to code all work on an end item and its components. The sixth and seventh characters are used in benchwork (off equipment) to allow identification of repairable subassemblies of major components.

When Discd. When discovered codes are single alphabetic characters which identify when the need for maintenance was discovered. These codes are applicable to the MAF only. There are two sets of when discovered codes, covering the following equipment categories: Aircraft and engines and aircraft maintenance support equipment.

When discovered codes relate primarily to conditions under which the malfunction or discrepancy was discovered rather than to the time in days or hours. For instance, code F (aircraft and engines) identifies a discrepancy or other need for maintenance that was discovered during the pilot's weekly inspection, while code F (aircraft maintenance support equipment) indicates that a need for additional maintenance was discovered during a period of unscheduled maintenance on the support equipment.

Type Maint. The type maintenance code is 1-character alphabetic code used to describe the type of work being accomplished (i.e., scheduled, unscheduled, supply support, etc.). Definitions and explanations of all these codes are contained in an appendix to the Standard Navy Maintenance and Material Management Program Manual.

Action Taken. The action taken code is a 1-character alphabetic or numeric code which describes the action that has been taken to correct the discrepancy. The action taken code "A" (Discrepancy Checked, No Repair Required) is used only in those cases where an inspection or operational check has been performed and the reported trouble cannot be duplicated or does not exist. In these cases the malfunction description code is "799" (No Defect) rather than a code that describes the reported discrepancy.

MAL. (Malfunction Description). The malfunction description code is a 3-character numeric code used to describe the malfunction occurring on or in the item identified by the work unit code on the maintenance data reporting forms. These codes are listed in alphabetical and numerical sequence in all Work Unit Code Manuals.

Items Proc. (Items Processed). Items processed, for the purposes of maintenance data reporting, is defined as the number of times that an action indicated by an action taken code is applied to the item identified by the work unit code recorded on an MDR form, or the number of times a support action is accomplished. EXAMPLE: Since the fuel nozzle of a jet engine is a coded item, replacement of five fuel nozzles would be documented as five items processed. In contrast to this, replacement of several tubes in an electronic assembly would be documented as one item processed with the work unit code identifying the electronic assembly being repaired, and the action taken code indicating repair.

Manhours. Entries in the manhours block of the MAF's represent all manhours expended by assigned personnel in completion of the work described on the source document. Hours and/or tenths worked multiplied by the number of men working equals total manhours. Time expended in exceptions of three-tenths of an hour or less is included in the total labor hours for the job. Exceptions which exceed three-tenths of an hour are not accounted for on maintenance action forms. These exceptions are charged to the proper labor distribution codes described later in this chapter. Entries in the manhour block of the maintenance data reporting (MDR) forms do not include labor hours for any work center other than the one submitting the document. For example, if two work centers jointly correct a discrepancy (same JCN) on the same aircraft or equipment, workers from each work center submit a source document with that particular work center's labor hours in the manhour block.

EMT. (Elapsed Maintenance Time). Elapsed maintenance time is defined as the actual clock time, in hours and tenths, that maintenance was being performed on a job. Although the EMT is directly related to job manhours, it is not to be confused with total manhours required to complete a job.

Block 16. Left blank. Use of this block is not currently prescribed.

Removed Item. This block will be completed on the four part MAF when a reparable component/part is removed from the equipment on which work is being accomplished. Enter the Reparable Item Code (RIC) and component serial number of the removed item in this block. If a RIC is not assigned, enter the manufacturer's code, serial number, part number (if more than fifteen (15) characters enter the last 15), and the meter reading to the nearest whole number. All meter readings will be prefixed with the letter "M." If no meter is installed, enter the time since new on the type equipment identified in block two (2) of the MAF.

Installed Item. Enter the Reparable Item Code (RIC) and component serial number of the installed item in this block. If a RIC is not assigned, enter the manufacturer's code, serial number, and part number (if more than fifteen (15) characters enter the last (15) of the installed item). Enter the meter readings in block 21.4 (blank block following the part number). All meter readings will be prefixed with the letter "M." If no meter is installed, enter the time since new on the type equipment identified in block two (2) of the MAF.

NOTE: The Removed/Installed item blocks on the single copy MAF shall be completed when recording cannibalization actions, and when reparable items are removed or reinstalled to facilitate other maintenance and recorded as separate maintenance actions. No entries will be made in these blocks on the single copy MAF when the Action Taken Code is L, M, N, S, or when removing items for test, inspection, or service and their subsequent installation.

Discrepancy. A narrative description of the reported discrepancy or work to be performed is entered in this space. The appropriate arrow below the word DISCREPANCY is circled to indicate the flying status of the aircraft.

Corrective Action. A narrative description of the work accomplished in compliance with the discrepancy block is entered here by the person accomplishing the job.

Entries Required. Applicable checkmarks in the entries required space are made when the action or discrepancy requires logbook or accessory record card entries. Maintenance control enters a checkmark in the configuration block when configuration of the equipment is affected. The person making the entries signs his name and rate in the adjacent signature block.

Corrected By. The worker or crewleader who accomplishes or supervises the repair signs his name and rate in this block.

Inspected By. The Quality Assurance Representative or Collateral Duty inspector who inspects the job for proper standards signs his name and rate in this block.

Supervisor. The work center supervisor or his assistant signs his name and rate in this block to indicate that screening and other appropriate action has been accomplished.

Repair Cycle Data. Enter the Julian dates for the following: 1. Removed; 2. Received material control; 3. Work started; and 4. Completed. Check the appropriate block to indicate if the item is ready for issue (RFI), requires rework (B COND), or is recommended for survey or salvage (R/S).

During the actual repair, if the job is interrupted for one or more days due to a lack of parts, enter the Julian date that the job goes AWP (Awaiting Parts) adjacent to block 5 or 7. Enter the Julian date that the parts are received adjacent to block 6 or 8. Blocks 5 and 6 are used the first time the job status is AWP and blocks 7 and 8 are used the second time the status is AWP. If the job status is AWP more than twice, dummy dates within the actual repair time are entered adjacent to blocks 7 and 8 to reflect the actual number of days lost due to the second and subsequent AWP status.

Failed Material. On the single copy MAF, enter the action taken code, malfunction description code, quantity, manufacturer's code, and part number of failed material in this block if the parts replaced during repair are parts, bits, and pieces that have failed in a major component. If the failed item is removed and replaced, enter action taken code "R" (removed and replaced). If the removed item is removed, repaired, and reinstalled, at the Organizational level of maintenance, enter action taken code "C" (repaired). It is intended that this block be utilized to record only primary items that have failed. It is not intended to be used for recording all items replaced (i.e., common hardware, nuts, screws, safety wire, etc.), nor is it to be used to record routine replacement of seals, gaskets, washers, fittings, etc., that are installed during overhaul or repair.

Accumulated Hours. The work centers use this block to record manhours and elapsed maintenance time (EMT) accumulated against a job. Whenever (1) completing a repair action, (2) turning in a supplementing document in support of the job, (3) making a work center change, (4) a reporting period ends, or (5) going

AWP, manhours and EMT are totaled in this section and entered in blocks 14 and 15 (near the top of the MAF) of the submitted document, after which the entries in the accumulated hours block are lined through to indicate they have already been documented.

Required Material. Whenever material is required to complete a maintenance action, it is requisitioned. In this section a line for each item ordered is filled in. Entered are the requisition number, manufacturer's code, part number, quantity, priority, date and time the material was ordered, and the date and time the material was received.

SUPPORT ACTION FORM (SAF)

The separate reporting of support type data is designed so that time expended in the accomplishment of repetitious type tasks that consume many manhours (but do not involve malfunctions, repairs, or condemnation action) may be easily identified, reported, and monitored. Manhours expended in support duties (such as aircraft refueling, engine or tire buildup, parachute packing, etc.) are documented on the support action form (SAF).

The SAF is a standard electric accounting machine (EAM) card which may be either handscribed or prepunched and preprinted, depending upon the desires and requirements of local maintenance managers. In either case, all support action forms are signed by the work center supervisor to indicate that screening has been accomplished. Figure 2-10 illustrates a handscribed support action form.

In order to identify manhours expended in specific categories of support type work, 3-character codes known as support action codes are used. Nine basic categories of support type work and the related code for each are listed on the back of the SAF form together with type maintenance codes.

Support codes may be further broken down within basic categories if deemed appropriate by local command; i.e., 011, 012, etc. In the event such a breakdown is desired, its use is controlled by the maintenance officer and managed by the analysis section. The areas of support work covered by each basic category are defined in detail in an appendix to the Maintenance and Material Management Manual (3M Manual).

Support action forms are filled out in the following manner:

Type Equipment Code. Enter a 4-character code that identifies the equipment on which support work is being accomplished; i.e., aircraft, engines, ground support equipment, etc. This code is found in appendix H of the 3-M Manual.

Action Organization. If the SAF is not preprinted and prepunched, enter the 3-character code that identifies the organization accomplishing the support action. This is the same alphanumeric organization code that was explained in connection with the maintenance action form.

Work Center Code. This, too, is the same numeric code series that is used with the MAF.

Maintenance Level. If the card is not prepunched and preprinted, enter the 1-character numeric code that identifies the maintenance level of the support action being performed. These codes are provided on the front of the SAF.

Action Date. The action date is the Julian date of the day the support action was completed.

Support Code. Enter the 3-character numeric code that identifies the category of work in which the support action was accomplished. These codes are listed on the back of the SAF.

Type Maintenance Code. This is a 1-character alphabetic code that identified the type of support maintenance that was accomplished.

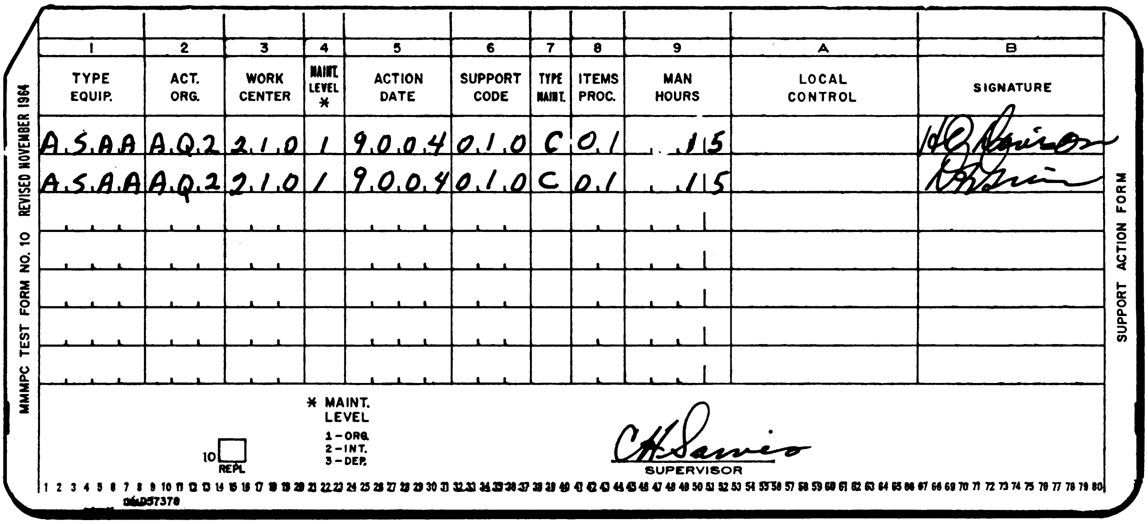
Items Processed. Entered here is the number of items processed, or the number of times that the support action identified in the support code block has been accomplished (i.e., 4 aircraft refueled, 3 preflight inspections accomplished, etc.).

Manhours. Enter the total number of manhours (in hours and tenths of hours) spent in the accomplishment of the support action documented on the same line of the card. A maximum of 999.9 manhours may be reported on one line entry.

Local Control. Provided for local use, if desired.

Signature. Enter the signature of the person documenting the support action.

Replenish. If preprinted, prepunched cards are used, enter a checkmark in the REPL block when more cards are needed. The maintenance officer controls and analysis section coordinates the production, volume, and distribution of preprinted prepunched cards.



MMMPC TEST FORM NO. 10 REVISED NOVEMBER 1964

1	2	3	4	5	6	7	8	9	A	B
TYPE EQUIP.	ACT. ORG.	WORK CENTER	MAINT. LEVEL *	ACTION DATE	SUPPORT CODE	TYPE MAINT.	ITEMS PROC.	MAN HOURS	LOCAL CONTROL	SIGNATURE
ASAA	AQ2	210	1	9004	010	C	01	.15		
ASAA	AQ2	210	1	9004	010	C	01	.15		

SUPPORT ACTION FORM

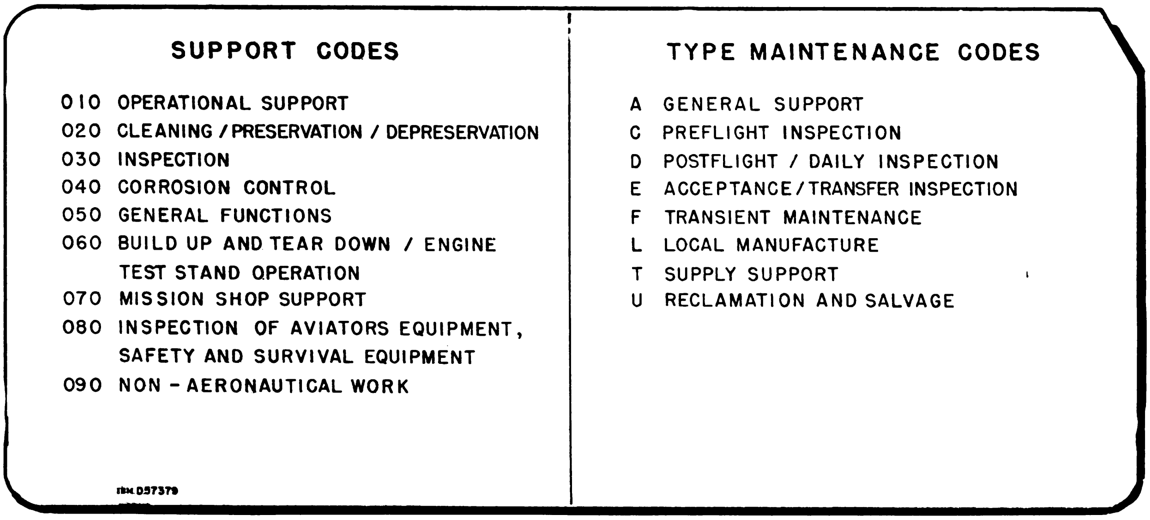
10 ☐ REPL

* MAINT. LEVEL
1-ORG.
2-INT.
3-DEP.

SUPERVISOR

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

IBM D57378



SUPPORT CODES

010	OPERATIONAL SUPPORT
020	CLEANING / PRESERVATION / DEPRESERVATION
030	INSPECTION
040	CORROSION CONTROL
050	GENERAL FUNCTIONS
060	BUILD UP AND TEAR DOWN / ENGINE TEST STAND OPERATION
070	MISSION SHOP SUPPORT
080	INSPECTION OF AVIATORS EQUIPMENT, SAFETY AND SURVIVAL EQUIPMENT
090	NON - AERONAUTICAL WORK

TYPE MAINTENANCE CODES

A	GENERAL SUPPORT
C	PREFLIGHT INSPECTION
D	POSTFLIGHT / DAILY INSPECTION
E	ACCEPTANCE / TRANSFER INSPECTION
F	TRANSIENT MAINTENANCE
L	LOCAL MANUFACTURE
T	SUPPLY SUPPORT
U	RECLAMATION AND SALVAGE

IBM D57379

AT.11

Figure 2-10.—Support action form (SAF).

The support action form is designed so that documentation may be completed by either the work center supervisor or the individual worker. Additionally, the card provides a multiple entry feature so that several different entries may be made on the same form.

MANHOUR ACCOUNTING AND FORMS

The effective use of available manpower is an important function of maintenance management. Manhour accounting is an important part of the maintenance data collection system. The purpose of collecting manhour data is to provide management with essential information necessary to plan and direct more efficiently the distribution of assigned personnel.

The Manhour Accounting System is based upon the "exception" principle; that is, only the deviations or exceptions from normal are reported. Through the use of master rosters, electric accounting machine cards, and machine processed reports, the system provides summaries of the hours expended by maintenance personnel during the normal working day or in an overtime status. Basically, the system is designed so that the normal working hours for each person assigned to the maintenance activity are allotted or assigned to work centers by types of labor at the beginning of each reporting period. Exceptions from these normal working hours, or labor types, are reported by use of manhour accounting cards. Data processing machines add or subtract the exceptions reported on the manhour accounting cards from the initial manhour allotment. These exceptions and the working hours allotted at the beginning of the period serve as the basis for the daily and monthly manhour accounting reports mentioned in the foregoing. These reports are forwarded to the maintenance officers and supervisors for validation and utilization. Each supervisor and worker must thoroughly understand the importance of the system, its operation, and the need for continual accuracy. Detailed instructions pertinent to the content and use of manhour accounting reports are contained in the following paragraphs.

At the beginning of each reporting period, generally the first of the calendar month, manhours are assigned to every work center to which personnel are assigned. These manhours are based on an 8-hour work day 5 days per week for every person assigned. Not included in these (original assigned manhours) are any hours for work on Saturdays, Sundays, or holidays during the month. If every person assigned to the work center could be continuously employed throughout the month during all the time available for work, there would be no need for manhour reporting, as the time would be accounted for on the maintenance action form. Since continuous employment is not possible, each worker must report what he did when he was not working during any period in excess of 20 minutes, or approximately three-tenths of an hour.

To simplify reporting of hours spent in a labor category other than that for which assigned, a group of prepunched, preprinted manhour accounting cards is provided for every worker assigned. A card is initiated each time a person excepts from normal for a period in excess of three-tenths of an hour and is completed at the end of the exception. The most frequent exceptions requiring the submission of manhour accounting cards are (1) each time a person is assigned to, or transferred from, a work center or organization, (2) each time a person performs work in other than his regularly assigned labor code, (3) each time a person is absent from his work center for nonmaintenance purposes such as watches, leave, sick, special liberty, etc., and (4) each time a person works overtime during a single work day or on his day off (holiday, Sunday, etc.).

Manhour accounting cards are, for the most part, prepunched and preprinted. However, handscribed cards have a place in the system. A handscribed card is illustrated in figure 2-11.

Handscribed manhour accounting cards are normally used to report (1) newly assigned personnel, (2) temporarily assigned personnel, (3) composite manhours involving more than one person, and (4) whenever prepunched, preprinted cards are not available.

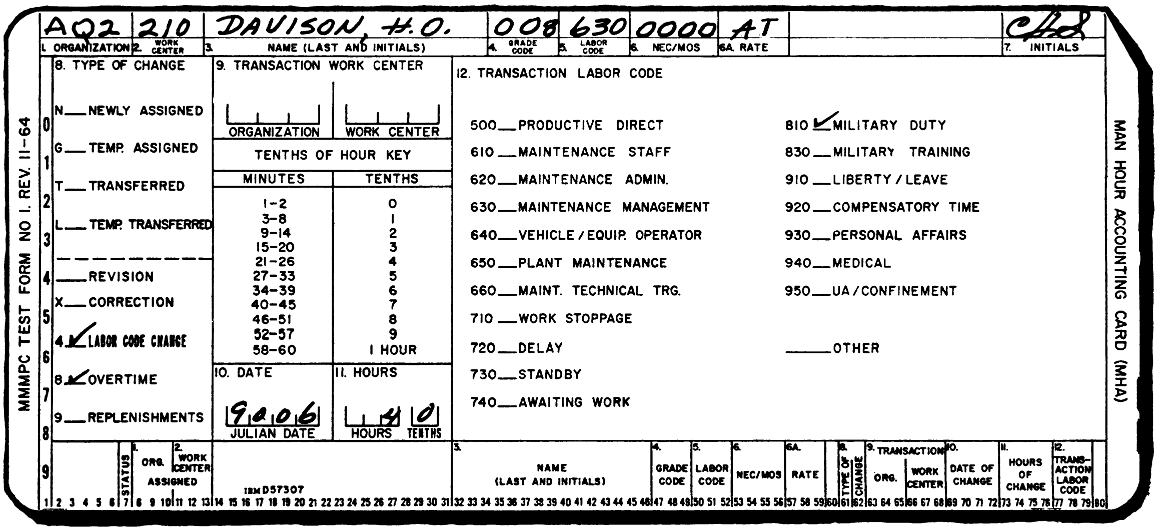
The use of the blocks and spaces on the manhour accounting card is discussed in the following paragraphs.

Block 1–Organization Code. The organization code is the same 3-character alphanumeric code described for use with the maintenance action form. Use of the code simplifies the identification of the unit to which a person or persons is/are attached or temporarily assigned. For example, TO1 is the code for NAS, Pensacola, Florida, and is much easier and faster to write in than the name of the activity.

Block 2–Work Center Code. The work center code identifies the functional area to which a person is assigned or temporarily assigned. A standard system of work center codes is prescribed. Therefore, a technician assigned to the avionics division at the Intermediate level of maintenance anywhere in the world will use the same work center code. Those technicians attached to the electronics branch at the organizational level of maintenance all use the same work center code.

Block 3–Name and Initials. This block is self-explanatory, except in the case of composite cards (used for two or more persons) enter the applicable number of men; i.e., "2 men," "4 men,", etc.

Block 4–Grade Code. This code is a 3-character numeric or alphanumeric code used to designate the grade and status of the individual



MMMPC TEST FORM NO I. REV. 11-64

AQ2	210	DAVISON, H.O.	008	630	0000	AT		C H S
1. ORGANIZATION	2. WORK CENTER	3. NAME (LAST AND INITIALS)	4. GRADE CODE	5. LABOR CODE	6. NEC/MOS	6A. RATE		7. INITIALS

8. TYPE OF CHANGE

N__NEWLY ASSIGNED

G__TEMP. ASSIGNED

T__TRANSFERRED

L__TEMP. TRANSFERRED

- - - - - - - - - - -

__REVISION

X__CORRECTION

4 ✓ LABOR CODE CHANGE

8 ✓ OVERTIME

9__REPLENISHMENTS

9. TRANSACTION WORK CENTER

ORGANIZATION

WORK CENTER

TENTHS OF HOUR KEY

MINUTES	TENTHS
1-2	0
3-8	1
9-14	2
15-20	3
21-26	4
27-33	5
34-39	6
40-45	7
46-51	8
52-57	9
58-60	1 HOUR

10. DATE

9206

JULIAN DATE

11. HOURS

4 0

HOURS TENTHS

12. TRANSACTION LABOR CODE

500__PRODUCTIVE DIRECT

610__MAINTENANCE STAFF

620__MAINTENANCE ADMIN.

630__MAINTENANCE MANAGEMENT

640__VEHICLE/EQUIP. OPERATOR

650__PLANT MAINTENANCE

660__MAINT. TECHNICAL TRG.

710__WORK STOPPAGE

720__DELAY

730__STANDBY

740__AWAITING WORK

810 ✓ MILITARY DUTY

830__MILITARY TRAINING

910__LIBERTY/LEAVE

920__COMPENSATORY TIME

930__PERSONAL AFFAIRS

940__MEDICAL

950__UA/CONFINEMENT

____OTHER

MAN HOUR ACCOUNTING CARD (MHA)

	STATUS	1. ORG.	2. WORK CENTER	IBM D57307	3. NAME (LAST AND INITIALS)	4. GRADE CODE	5. LABOR CODE	6. NEC/MOS	6A. RATE		8. TYPE OF CHANGE	9. TRANSACTION ORG. WORK CENTER	10. DATE OF CHANGE	11. HOURS OF CHANGE	12. TRANSACTION LABOR CODE	
1 2 3 4 5 6	7	8 9 10	11 12 13	14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31	32 33 34 35 36 37 38 39 40 41 42 43 44 45 46	47 48 49	50 51 52	53 54 55 56	57 58 59	60	61 62	63 64 65 66 67 68	69 70 71 72	73 74 75 76	77 78 79	80

Figure 2-11.–Manhour accounting card.

AT.12

being reported. All military grade codes start with 0 and range upward from 001 (recruit) to 019 (captain/colonel). All civil service codes start with G and correspond to their pay status. For example, a GS-1 code is G01 and the top is G14 for a GS-14. Grade codes C01 through C04 are special civilian codes and are provided for use where necessary as directed by the major command.

Block 5–Labor Code. Labor codes in five major categories are prescribed for use here. Manhour expenditures are charged to the labor code which best describes the type of labor performed or how a worker's time was spent. The five major categories are as follows: Direct Labor (500), Productive Indirect (600), Nonproductive (700), Duty Absence (800), and Nonduty Absence (900). All of these code groups except Direct Labor employ digits other than 00 to more precisely picture what was done. For example, Duty Absence (800) is further divided into Military Duty (810) and Military Training (830).

Block 6–NEC/MOS. In this block is entered the primary Navy Enlisted Classification Code or Marine Corps Military Occupation Specialty Code for newly assigned personnel only. Naval Officer Billet Codes (NOBC) or designators may be used for officers. If desired, a person's rating may be entered in block 6a.

Block 7–Initials. The initials of the work center supervisor are entered here to indicate that screening has been accomplished. Every worker assigned to a work center is responsible for submitting his own cards, except when he is absent at the end of a reporting period. In such cases, the supervisor submits the necessary cards. It is the responsibility of the work center supervisor to see that every card submitted by everyone is correct in every detail.

Block 8–Type of Change. It must be kept in mind that maintenance manhours are not reported on manhour accounting cards. Whenever the normal routine (which is set up on the electric accounting machines) varies or changes for any of the reasons listed in block 8, a card must be submitted AFTER the change occurs. For instance, after being temporarily assigned or transferred or immediately after working overtime. A check (✓) in a block 8 space is nearly always accompanied by an entry in block 9, 10, 11, and/or 12. An exception to this is "Replenishments." A preprinted, prepunched card, checked in the "Replenishments" space, is submitted by the man concerned when the number of preprinted, prepunched cards remaining in his personal stack is less than 10. The data center will forward him a new supply the next day. The relationship of block 8 spaces to blocks 9, 10, 11, and 12 will be discussed in conjunction with the coverage of the latter group of blocks.

Block 9–Transaction Work Center. Block 9 is used in conjunction with the "Temporarily

Assigned" and "Temporarily Transferred" categories in block 8. When a man is temporarily transferred to another work center, the change requires the initiation of two cards, because it involves two work centers. At his permanent work center he initiates a card checked "Temporarily Transferred" in block 8, and his temporary work center code is entered in block 9. When he arrives at his temporary work center he initiates the second card. On this card, "Temporarily Assigned" is checked in block 8, and the code number for his permanent work center is entered in block 9.

Block 10–Date. Block 10 is not filled in until the temporary work assignment is completed. At that time the Julian date is entered in this block, identifying the day the exception was completed.

Block 11–Hours. Upon completion of the exception, the number of hours and tenths of hours involved in the exception are entered here. Space is provided for 999.9 hours to be reported on a single card. When "Newly Assigned" (block 8) is checked, the number of hours reported is the number of hours of normal working time remaining in the reporting period. If "Temporarily Assigned" is the reason for submitting the card, the total elapsed number of working hours while so assigned is reported. The exception to this is when a temporary assignment extends into the next reporting period. In such cases a temporarily assigned card is submitted at the end of the month with that month's hours reported and, when the exception ends during the next reporting period, another temporarily assigned card is submitted to report only the number of temporarily assigned hours elapsed in that reporting period.

If "Transferred" (block 8) is the reason for submitting a manhour accounting card, the number of working hours remaining in the reporting period is reported. It will be recalled that the total number of working hours available for a reporting period for a work center is obtained by multiplying the number of men assigned by 5 days per week and 8 hours per day. When a person is transferred during the reporting period, all the working hours that he would have worked had he remained must be subtracted from the work center's total manhours available. The same reasoning holds true for "Temporarily Assigned" where the number of hours in this category is added to the temporary work center's totals and "Temporarily Transferred" where the number of hours away is also deducted from the permanent work center's totals.

Block 12–Transaction Code. An entry in this block is mandatory if "Labor Code Change" or "Overtime" has been checked in Block 8. A checkmark is entered to identify the labor code in which manhours were expended. If the "Other" line is checked, the appropriate subcode promulgated by the analysis section is entered in the space provided. The majority of manhour accounting cards submitted are "Labor Code Change."

TECHNICAL DIRECTIVES COMPLIANCE FORM

The Technical Directive Compliance Form (TDCF) is a single page form that is also used to document all technical directive maintenance actions. The TDCF is used by reporting custodians for preplanning workload and material requirements and for configuration accounting. Data obtained from these forms allows identification of all direct manhours expended complying with technical directives.

Unlike the MAF and SAF, the TDCF is originated by maintenance or production control. It is normally initiated upon receipt of each approved applicable technical directive.

There are several factors which must be considered in determining the number of copies required. In all cases, an original and one copy must be originated. If parts or kits are required for compliance, one copy is forwarded to material control. The original is forwarded to the primary work center when required material is available and the directive is scheduled for completion. If more than one work center is involved, one copy is forwarded to each assisting work center. One copy is held in suspense by maintenance control until the completed original is received from the work center.

CONFIGURATION CONTROL FORM

The Configuration Control Form (CCF) is a single page multiple entry document which is used to report the part number change of reparable items as a result of technical directive compliance on an aircraft, engine, or other selected item of equipment. This form is also used to report the removal and the installation of all items listed on the respective type equipment Configured Item List. A CCF is not required to report the removal and reinstallation of the same part number and serial numbered item on the same equipment when both actions take place as a single maintenance action. The CCF is normally initiated by maintenance control and completed by the primary work center or maintenance control.

NOTE: Configured items are selected items which require configuration status accounting. Items selected normally affect mission capability and can be interchanged with a similar item that results in a different mission capability, or are management attention or time compliance items. Many of the data blocks on the CCF are transcribed directly from the corresponding blocks on the TDCF or the MAF.

UNSATISFACTORY MATERIAL CONDITION REPORT (UR)

The Unsatisfactory Material/Condition Report, hereafter called UR, is a four-part, carbon interleafed, snap-out form. All activities concerned with maintenance of naval aircraft should use the UR's to report SAFETY, URGENT, and SPECIAL SITUATIONS.

The UR provides a system for submittal of specific information concerning failures, material defects, and other critical situations affecting naval aeronautical equipment which require prompt attention and corrective action. The UR is used for special situations as follows:

1. Report hazards to flight safety. The report in such instances serves as a followup to a Flight Safety Message in accordance with NavAir 4700.2 Series Instructions.
2. Report errors or omissions in aircraft and equipment manuals.
3. Report aeronautical equipment found in an unsatisfactory condition as a result of design deficiency, faulty manufacture, faulty overhaul, or faulty preservation and packaging.
4. Make special reports on any weapons system or equipment specifically requested by the Naval Air Systems Command for special reliability studies.

The front page of the UR contains instructions for the completion of the form. Using a typewriter or ball point pen, fill out the required spaces. The second page of the completed form is forwarded to the Naval Technical Services Facility, and the third page is retained by the originating activity for record purposes. The tag copy (fourth page) is attached to the material being turned in to supply or released for investigation. In the event that the material is not turned in to supply or released for investigation, the tag copy is discarded.

VISUAL INFORMATION DISPLAY SYSTEM (VIDS)

The Visual Information Display System (VIDS) is a time charting management tool which provides a graphic display of vital, up-to-date information on a continuing basis. The system correlates all aircraft status information, particularly awaiting parts and flyable discrepancies, and assigns a relative importance to each item. Additionally, the system displays the amount of time required to perform any maintenance and the number of personnel available and engaged in work. The ability to review the overall situation and determine what resources are available enables the maintenance officer and maintenance control officer or supervisor to more effectively and efficiently carry out his duties. This information is displayed on specially configured cardex type display boards.

DISPLAY BOARDS

VIDS boards consist of enlarged cardex type pockets scaled horizontally to represent hourly time periods. Each pocket is overlapped by the one above so that approximately a 3/8-inch strip is visible at the bottom of the pocket. Boards are available in three sizes–100 pocket (40" x 40"), 50 pocket (40" x 26"), 25 pocket (40" x 14"), and in three standard configurations. The configurations are as follows:

1. Organizational, flight maintenance board. This board provides current status of each aircraft plus displaying scheduled/unscheduled maintenance, including outstanding flyable discrepancies, parts on order, scheduled flights, and aircraft configuration. The current and projected workload of each work center and the number of labor code 500 personnel available for work are also displayed on this board.

2. Material control status board. Outstanding material requisitions are displayed on this board by aircraft modex, work center, and document number.

3. Work center board. The work center board displays the work assignments by name in the work center plus providing space for individual technical qualifications record. Space is also provided for pending assignments, not assigned tasks, and those in an AWP (aircraft awaiting parts) status. The top pocket is configured to show the status of special support equipment (SSE) required by the particular work center.

IMPLEMENTATION PROCEDURES

To make the implementation phase as smooth as possible, a thorough indoctrination of the maintenance/material control personnel and work center supervisors is necessary. All problems concerning operating procedures, information flow, and communication procedures should be resolved prior to the implementation date. Certain steps are necessary if the transition is to be made in an orderly manner with minimum disruption of the maintenance effort.

Information Display Requirements

Efficient management of the maintenance effort requires certain information concerning the resources of the activity be available. The range and depth of information requirements are determined by such factors as mission, size, and physical layout of facilities. For purposes of standardization and to insure that the minimum information requirements are displayed, the following guidelines should apply:

1. Maintenance control.
    a. Inventory of aircraft.
    b. Aircraft configuration.
    c. Aircraft airframe / engine / component/time.
    d. Aircraft / equipment discrepancy status.
    e. Work center loading.
    f. Projected flight and maintenance requirements.
2. Material control.
    a. Outstanding requisitions by aircraft and priority.
    b. Outstanding requisitions not identified to a specific aircraft.
    c. Master register listing by supply document number.
3. Work center.
    a. Personnel status.
    b. Training/qualification record.
    c. IN WORK discrepancies and personnel assigned.
    d. AWP and pending discrepancies.

OPERATING PROCEDURES

There are two approved methods of operation for the Organizational Maintenance Control VIDS. Both methods are in consonance with current OpNav directives and are adaptable to any type activity. With either method, the primary consideration is placing maintenance control in CONTROL OF MAINTENANCE.

Time Charting Method

This method is a 3-day projection–title columns with Julian date; i. e., 9060, 9061, and 9062, and continue sequence as workdays progress. At the beginning of each shift, the maintenance control supervisor will verify his status board(s) with the various work centers. Each work center supervisor will inform him of the number of labor code 500 personnel available for work. These numbers will be indicated by the use of manpower indicators on the work center sections of the board.

Each discrepancy will be transcribed on an appropriate colored maintenance control register along with other pertinent information available at that time. Red registers will be used for discrepancies that place the aircraft in a nonflyable status. Blue registers are used for flyable discrepancies that do not place the aircraft in a reduced material condition (RMC), and an orange register for discrepancies that cause the aircraft to be placed in a reduced material condition.

The maintenance control supervisor will determine whether the affected work center(s) has the capability to handle the discrepancy at the present time. In making this decision he should utilize the manpower information displayed on the work center section, the present workload, and priority of the IN WORK and

PENDING discrepancies. Based on his decision, the following procedures will be used.

1. Work center has capability. Maintenance control will transmit pertinent information to the affected work center(s). At this time, the work center supervisor will provide maintenance control with the estimated time of completion (ETC), work unit code, and number of personnel that will be assigned to the task. This information is entered in the appropriate spaces of the register. An Equipment Statistical Data (ESD) card will be initiated to indicate a change in the aircraft condition. The colored tabs at the bottom of the register, in excess of the ETC, are folded under. Copy 1, along with the ESD card, is placed in the aircraft pocket or pockets under the appropriate day and time frames. Copy 2 is placed in the appropriate work center pocket in the same manner, and the "men assigned" sliding tab is adjusted to indicate number of personnel assigned. Copy 3 will be forwarded to Quality Assurance for information purposes.

2. Work center does not have capability at present time. Maintenance control will indicate on the register that the discrepancy is in an AWM (aircraft waiting maintenance) status and will schedule the work at a later date and/or time. Copy 1 will be placed in the aircraft pocket, and copies 2 and 3 in the work center pocket under the appropriate date and time frame. An ESD card will be initiated and placed in the aircraft pocket. When the discrepancy is scheduled IN WORK, procedures described above will be utilized.

The register will remain on the board in an IN WORK status until the discrepancy is completed or unless the aircraft goes AWP or AWM. AWP and AWM status are described as follows:

AWP. The existing ESD card is closed out and a new one initiated to show current status. A black tab is placed in front of the register to provide visual recognition of the AWP status. Copy 2 of the register is moved to the AWP section of the work center board. When material is received, discrepancy is rescheduled for work.

AWM. When maintenance control determines that a work center must go AWM on a discrepancy, the pertinent information will be entered. The discrepancy will be rescheduled at a later date and/or time and register copies 1 and 2 will be moved on the board to the appropriate time frame. These registers can be flagged with an appropriate color for easy identification.

When maintenance control is notified that a discrepancy has been corrected, the registers (copies 1 and 2) will be removed from the board and copy 2 destroyed. Pertinent information will be entered in the appropriate blocks of copy 1.

Copy 1 should be retained in a temporary file until the MDR document passes through maintenance control. At that time, all necessary information is verified and then the register is filed in accordance with existing instructions. Insure that the ESD card reflects the current status of the aircraft.

Current Discrepancy Status Display Method

This method utilizes three columns–PENDING, IN WORK, and AWP–each encompassing one 24-hour period. At the beginning of each shift, the maintenance control supervisor will verify his status board(s) with the various work centers. The supervisor will then determine which work centers have capability to handle incoming discrepancies. In making this decision, he should utilize the manpower information displayed on the work center section, the present workload, and priority of the IN WORK and PENDING discrepancies. Based on his decision, the following procedures will be used:

1. Work center has capability. Maintenance control will transmit pertinent information to the affected work center(s). At this time, the work center supervisor will provide maintenance control with the estimated time of completion (ETC), work unit code, and number of personnel that will be assigned to the task. This information is entered in the appropriate spaces of the register. An Equipment Statistical Data (ESD) card will be initiated to indicate a change in the aircraft condition. The colored tabs at the bottom of the register, in excess of the ETC, are folded under. Copy 1, along with the ESD card, is placed in the aircraft pocket under the heading IN WORK and time frames. Copy 2 is placed in the appropriate work center pocket in the same manner (column and time frame),

and the "men assigned" sliding tab is adjusted to indicate number of personnel assigned. Copy 3 will be forwarded to Quality Assurance.

2. Work center does not have capability at present time. Maintenance control will indicate on the register that the discrepancy is in an AWM status and will schedule the work at a later date and/or time. Copy 1 will be placed in the aircraft pocket under the heading PENDING. Copies 2 and 3 are placed in the appropriate work center pocket under the same heading.

An ESD card will be initiated and placed in the aircraft pocket. When the discrepancy is scheduled INWORK, procedures described under work center capability will be utilized.

When a discrepancy has been scheduled IN WORK, the register will remain on the board under the heading IN WORK until the discrepancy has been completed or it is necessary to go AWP or AWM.

AWP. When maintenance control determines that a work center must go AWP on a discrepancy, copy 1 is placed in the aircraft pocket under the heading AWP. Copy 2 is placed in the appropriate work center pocket under the same heading. When the material is received, the discrepancy is rescheduled for work. Insure that the ESD card reflects the current status of the aircraft.

AWM. When maintenance control determines that a work center must go AWM on a discrepancy, the pertinent information will be entered in the appropriate block of copy 1. Both copy 1 and the ESD card are then placed in the aircraft pocket under the heading PENDING. Copy 2 is placed in the appropriate work center pocket under the same heading. The discrepancy will be rescheduled at a later date and/or time and the registers (copies 1 and 2) will be moved to the appropriate pockets under the heading IN WORK. Copy 1 will be updated by entering the IN WORK time in the appropriate blocks.

When maintenance control is notified that the discrepancy has been corrected, the registers (copies 1 and 2) will be removed from the board and copy 2 destroyed. Pertinent information will be entered in the appropriate blocks of copy 1.

Copy 1 should be retained in a temporary file until the source document is received in maintenance control. At that time, all necessary information is verified and then the register is filed in accordance with existing instructions. Insure that the ESD card reflects current status of the aircraft.

Maintenance Control Information

The number of the assisting work center(s) is written in the appropriate block when a discrepancy is transcribed on a maintenance control register. A copy 2 register of the same color as the primary register is made out for each assisting work center and placed in the appropriate work center section. As each assisting work center completes their portion of the discrepancy, the source document that is submitted will be verified with the copy 1 register and that particular work center will be crossed out. The initials of the person calling in the completion will be written above the work center number.

ESD cards can be placed on the VIDS board by either placing the card behind copy 1 of the register or inserting the card in the pocket on the extreme left side of the board. In this manner, the status block of the card is visible.

Work Center Information

When a discrepancy is received by the work center supervisor, pertinent data is recorded on the work center register. The supervisor informs maintenance control of the ETC, WUC, and the number of men that will be assigned to the task. The register is then placed in the pocket under the heading IN WORK and parallel to the name of the person given responsibility for the task. A distinguishing tab (or number) can be placed in any corresponding pocket(s) of other personnel assigned to the repair action. The register remains on the board until the discrepancy has been completed or it is necessary to go AWP or PENDING. If either of these two conditions occur, the register is removed from the IN WORK section, annotated with the proper information, and maintenance control is notified of the work status change. The register is then placed either in the AWP or in the PENDING section of the work center board. When the material has been received or the task rescheduled by maintenance control, the register is updated and placed in the IN WORK section of the board. When the task has been completed, the work center register is completed and the pertinent information is passed to maintenance control.

The completed register is verified against the completed source document prior the document being passed on to maintenance control. The register will be retained in a temporary file until verification of the daily MDR readout is accomplished, then filed in accordance with existing instructions.

Calendar Maintenance Procedures

When an aircraft is inducted into a calendar inspection, maintenance control will initiate an appropriate maintenance control register with a controlling JCN. Copy 1, along with an ESD card, is placed in the appropriate aircraft pocket. Copy 2 is placed in the pocket of work center 140 to indicate one aircraft inducted for inspection. All registers are removed from the VIDS board (copies 1 and 2) and are consolidated, by JCN order, on an outstanding discrepancy control form. The control JCN and maintenance control registers, with the outstanding discrepancy control forms, are issued to the calendar maintenance supervisor.

Upon induction of an aircraft into calendar inspection, the calendar maintenance supervisor will perform all maintenance control functions until completion of the inspection. All pending registers will be displayed in the same manner as maintenance control's board; i.e., copy 1 in the aircraft pocket, and copy 2 in the applicable work center pocket. When a look phase or a fix phase register is initiated, they also will be displayed in the same manner. Upon notification of a task, each applicable work center supervisor will initiate a work center register and will display them in accordance with work center supervisor's procedures. The calendar maintenance supervisor must notify maintenance control of any change that affects ESD reporting. When the inspection is completed, the control document will be signed off. All flyable discrepancies that are still outstanding should be listed on an outstanding discrepancy control form by JCN order. All registers (copies 1 and 2), the outstanding discrepancy control form, and the control document will be turned in to maintenance control.

When maintenance control is notified the calendar inspection has been completed, registers (copies 1 and 2) are then removed from the VIDS board. Annotate copy 1 and file in accordance with existing instructions, and destroy copy 2. Update the ESD card to reflect the current status of the aircraft. Place a flight card in the aircraft pocket with a red tab to indicate a test flight is required. Display all flyable discrepancies (copies 1 and 2) in the aircraft pocket and appropriate work center sections of the maintenance control board.

CHAPTER 3

SAFETY

In the performance of his normal duties, the naval avionics technician is exposed to many potentially dangerous conditions and situations. No training manual, no set of rules or regulations, no listing of hazards can make working conditions completely safe. However, it is possible for the technician to complete a full naval career without serious accident or injury. Attainment of this goal requires that he be aware of the main sources of danger, and that he remain constantly alert to those dangers. He must take the proper precautions and practice the basic rules of safety. He must be safety conscious at all times, and this safety consciousness must become second nature to him.

Much pertinent safety information is contained in Rate Training Manuals. Of particular worth among these manuals are Airman, NavPers 10307-C, and Standard First Aid Training Manual, NavPers 10081-B. In addition, directives concerning safety are published by all major commands on those specific hazards and procedures falling under the cognizance of those commands. The Chief of Naval Operations has recently issued a listing of specific safety precautions compiled by the Navy Department. This publication cross references safety directives by subject matter and by the identifying designation.

The purpose of this chapter is to indicate some of the major hazards encountered in the normal working conditions of the technician, and to indicate some of the basic precautions that must be observed. Although many of these hazards and precautions are general and apply to all personnel, some of them are peculiar or especially applicable to avionics maintenance personnel.

SAFETY PRECAUTIONS

Most accidents which occur in noncombat operations can be prevented if the full cooperation of personnel is gained, and if care is exercised to eliminate unsafe acts and conditions. In the following paragraphs, some general safety rules are listed. These rules apply to personnel in all types of activities, and each individual should strictly observe the following precautions as applicable to his work or duty:

1. Report any unsafe condition or any equipment or material which he considers to be unsafe.
2. Warn others whom he believes to be endangered by known hazards or by failure to observe safety precautions.
3. Wear or use available protective clothing or equipment of the type approved for safe performance of his work or duty.
4. Report any injury or evidence of impaired health occurring in the course of work or duty.
5. Exercise, in the event of any unforseen hazardous occurrence, such reasonable caution as is appropriate to the situation.

Safety precautions in this chapter are not intended to replace information given in instructions or maintenance manuals. If at any time there is doubt as to what steps and procedures to follow, consult the leading petty officer.

AVIATION SAFETY

For purposes of this discussion, the term AVIATION SAFETY is used in connection with all functions and operations having to do with aircraft and with materials and equipment used in connection with aircraft, hangars, parking areas and ramps, and flight lines and taxiways.

Hazards

Among the major hazards present in aviation activities are the following:

1. Fire or explosion caused by the application of external or internal power to an aircraft which is in some state of malfunction or disrepair, or undergoing maintenance or modification; or which create explosive vapors; or which have electrical short circuits.
2. Personal injuries sustained in falling from aircraft or workstands, being burned or blown about by jet blast or prop wash, being struck by objects blown about by jet blast or prop wash, being sucked into jet intakes, or being struck by propeller or rotor blades.
3. Being run down or over, due to lack of alertness to the movement of taxiing aircraft or ground equipment vehicles.
4. Explosion of aircraft batteries due to improper charging methods or to current overloading on ground tests within an aircraft.
5. Injuries (especially common during the hours of darkness) caused by encounter with tiedown lines, padeyes, chocks, protruding parts of aircraft or other equipment, or other such items about a deck or ramp.
6. Canopy, ejection seat, ordnance, and other "wrong switch at the wrong time" type accidents.
7. Misuse of, and abuse to, flight safety equipment, parachutes, "Mae Wests," liferafts, etc.
8. Accidents caused by careless workmanship, such as leaving tools or other extraneous materials in aircraft bilges, engine nacelles, intake or exhaust ducts, or movable parts of aircraft structures.

Precautions

Many safety precautions are of general nature and apply to all types of aircraft; however, others vary in specific details between specific models. It is imperative that all personnel whose duties take them into the vicinity of aircraft be familiar with both general safety precautions and with the specific precautions for the model with which they are associated. The following partial list of safety precautions is not intended to represent a complete listing. It is intended to serve merely as a guide to illustrate the general types of safety items which must be included in the safety education and training programs of all aviation activities.

1. Appropriate warning signs must be placed in or around aircraft or work areas whenever and wherever an unsafe condition is known or thought to exist. Strict attention and adherence to the signs must be enforced.
2. Smoking regulations and prohibitions must be observed and strictly enforced. Since explosive vapors may be ignited from any source of open flame or from electrical arcing, these conditions are subject to the same restrictions as smoking.
3. Radio and radar transmitters should not be trained on potentially explosive areas or on personnel, nor should they be operated in close proximity to flammable or explosive materials or vapors. This hazard is discussed in considerable detail in a later portion of this chapter.
4. Storage batteries or electric cables should not be disconnected or removed from their circuits in any enclosed space immediately following flight or fueling operations without first ventilating the space to remove accumulated vapors. All switches should be opened and all electric power disabled prior to disconnecting batteries or electric cables.
5. Combustible materials such as rags and clean waste should be stowed in covered metal containers. Used waste and rags should never be discarded near aircraft; they should be put into plainly marked metal containers.
6. Aircraft should be parked with parking brakes set, chocks in place, and tiedowns installed. If manila rope is used for tiedowns, some slack must be allowed; manila rope will shrink when wet, and may result in undue strain on the aircraft.
7. During jet engine runup, foreign objects may be drawn into the intake ducts, causing damage to the engine compressor section and the danger of flying debris from the exhaust section. During maintenance procedures involving engine operation, a careful inspection of the intake ducts and surrounding areas must be performed to insure the absence of foreign objects; and engine air intake safety screens must be properly installed. Parking areas, turnup areas, taxiways, and runways

must be kept clean and free of stones, hardware, and other foreign objects.

MACHINERY

When working with, on, or around machinery, be constantly alert to moving parts. Never reach into the path of moving parts of a machine, either with the hands or with any other item. Always follow prescribed procedures in making adjustments on machinery while in operation; if at all possible, make the adjustments with the machinery shut down. Never wear loose, baggy, or ill-fitting clothing in the immediate vicinity of machinery. Remove rags, papers, etc., from pockets; remove ties, wristwatches, rings, etc.; button shirt sleeves; make sure dogtags are inside the undershirt or removed completely.

ELECTRICAL EQUIPMENT

The safety precautions and considerations listed above for machinery apply also to electrical equipment. In addition to the danger of being grabbed or struck by moving parts, electrical equipments also present the dangers of fire, explosion, electrical shock, and burns.

Electrical equipment should never be operated in areas where explosive vapors are present or suspected, unless the equipment is of the special explosion-proof designs made expressly for use in such areas.

When working with, on, or around electrical equipment, avoid contact with power circuits. If it is necessary to work on energized circuits or on electrical equipment while in operation, use adequate protective materials (rubber gloves, insulated tools, insulating matting, etc.) and extreme care. Never work on electrical equipment when standing in water, when perspiring heavily, or when in contact with metal decks or other metallic structures or equipment. When preparing to work on deenergized electrical circuits, make sure the power switch is off, and then use a grounding probe to eliminate any residual charge that may exist in the circuit.

These precautions apply to low voltage equipments as well as to high voltage equipments. It must be remembered, in connection with electrical shock and burns, that it is the current that does the damage, not the voltage.

VOLATILE FLUIDS

Volatile fluids are liquids which evaporate rapidly at relatively low temperatures. In this discussion, the term will be used to include pressurized gases escaping from their containers. In safety considerations, two main types of fluids must be considered: First, those which result in explosive vapors; and second, those which are toxic.

Explosive Vapors

Aviation fuels, alcohol, painting materials and supplies, insulating varnish, certain cleaning supplies, and many industrial gases produce potentially explosive vapors when allowed to accumulate in closed spaces. The hazards relating to these materials are associated with the FLASHPOINT of the liquid. This is the lowest temperature at which the liquid gives off vapor which accumulates near the surface in sufficient quantity to form a combustible mixture with air. Although liquid oxygen does not have a flashpoint, the explosive effect is the same. Almost any material that will oxidize becomes highly explosive when in the presence of liquid oxygen.

The flashpoint varies with specific materials. Personnel working with volatile materials should become familiar with the characteristics of the particular materials with which they are associated. They should know the flashpoint and also the concentration which constitutes a combustible mixture.

A general safety rule regarding explosive vapors is to always provide adequate ventilation so as to prevent accumulation of vapors, or to dispel accumulated vapors prior to operating electrical equipment in that space. The presence of an odor of gasoline or other flammable or explosive vapors is not a reliable indicator of flammability, since the ability to detect odors varies between observers.

Toxic Vapors

Some liquids, upon evaporating, produce vapors which are harmful to personnel. Carbon tetrachloride is an effective solvent, an excellent cleaning material, and an excellent fire extinguisher—but it produces vapors so toxic that its use for any purpose is specifically prohibited by Navy directives. Many other materials are either prohibited or very rigidly limited for use. In most instances, the precautions are listed on the container. These precautions must at all times be rigidly adhered to and enforced. Safe substitutable materials should be used whenever permissible.

Safety considerations require that all personnel make themselves familiar with the hazards involved in the use of all materials. Toxic materials and vapors may be easily detectable, or they may be almost completely undetectable; they may act very slowly, or they may act almost instantly; they may cause discomfort, temporary damage, permanent injury, or even death; they may or may not be explosive in addition to being toxic. Toxic vapors may produce headache, dizziness, nausea, and a general feeling of illness. They may cause a gradual loss of interest, energy, or awareness. They may result in unconsciousness. They may cause temporary or permanent damage to the respiratory system, eyes, or skin. They may cause paralysis or death. Avoid prolonged exposure to vapors not known to be safe.

CONFINED SPACES

When personnel are working in confined spaces, adequate ventilation must be provided. This includes oxygen for normal breathing, cooling to prevent heat exhaustion, air movement and exchange to prevent hazardous accumulations of vapors, and an additional or alternate source of ventilation for use in the event of emergency. Whenever a worker is sent into a confined space for any reason, provisions should be made in advance for his rescue in the event of accident or emergency. These provisions include the use of safety lines for locating the worker and for retrieving him from the space. Some means of communication must be established so that the conditions existing inside and outside the space may be made known to personnel concerned. A safety man must be provided to keep a constant check on the condition of the space and the worker, and he must be prepared to sound the alarm for additional help or to render assistance to the worker in the confined space, as required.

Fumes tend to collect in confined spaces, so the condition of the space should be checked prior to entry. The worker should also check conditions as he enters and monitor them during his stay. He should maintain constant communication with his safety man and inform him of any abnormal conditions that may exist.

Equipment used by personnel working in confined spaces is a matter of considerable importance. Enough light should be provided so that he can see clearly what he is doing. The light provided should be insulated so that it does not present a shock hazard (confined spaces are usually quite warm, and a safety light produces additional heat, so perspiration may become a serious problem). When possible, explosion-proof equipment should be used in confined spaces, and protective clothing should be used if toxic fumes are known or suspected to exist within the space.

TOOLS

To prevent tragic and unnecessary damage to aircraft or equipment, loss of human life, or personal injury, it is necessary to develop and to practice careful, safe, and clean work habits. All tools and equipment used should conform to Navy standards as to quality and type, and should be used only in the manner and for the purpose intended. All tools in active use should be maintained in good repair, and all damaged or nonworking tools should be replaced through supply channels. When a job is completed, or when work is interrupted, all tools should be counted and returned to the toolboxes or to the tool issue room. This should be done as carefully as a surgeon accounts for all his instruments following a major operation.

Handtools

Detailed information on the use, care, and selection of general tools is contained in the Rate Training Manual, Basic Handtools, NavPers 10085-A. Chapter 7 of this course presents information on specific tools used by avionics technicians. Appropriate study and frequent review of these sources are recommended for all personnel using or supervising

ls. The following paragraphs point
lpractices sometimes found among
personnel.
uld be taken in selecting the proper
r cutters for the specific job. Pliers
hould not be used on nuts or pipe
ches are made for this purpose.
; short pieces of wire, rivets, or
als, take precautions that the clip-
t fly and cause eye injury; wear
e careful.
driver used for electrical work
a nonconducting handle. Screw-
ld never be used as a substitute for
isel, or prybar. The screwdriver
uld be of the proper type and size
w on which it is to be used. The tip
driver should be kept in the proper
ndition—broken or defective screw-
uld be discarded and replaced.
s should be used only if they are in
n and if they are right for the job.
wrench as a hammer, and never put
on the handle to increase torque.
e wrench should be used so that the
w is forward in the direction of
n working in close spaces, use a
ill not endanger the fingers and
he wrench should slip.

wer Tools

able power tools should be carefully
rior to use to insure that they are
the proper state of repair. Switches
ate in a normal manner, cords should
defects, and the casings of all
driven tools should be properly
grounded. When using or preparing to use any portable power tools, the cords, hoses, or cables should not be allowed to kink, nor should they be left where they may be run over or constitute a tripping hazard. They should not be allowed to come into contact with oil, grease, hot surfaces, chemicals, or sharp objects. When damaged, they should be replaced, never patched with tape.

Sparking electric power tools or equipment should never be used in any space where flammable vapors, gases, liquids, or explosives are suspected. When unplugging electrical tools or equipment from receptacles, first turn the equipment off, then grasp the plug (not the cord) to remove the plug from the receptacle. Stow the tool in its proper place.

ELECTRIC DRILL.—When using a portable power drill, grasp it firmly during operation to prevent bucking or breaking loose with possible injury to the user or damage to the tool or material. Use only straight, undamaged, and properly sharpened drill bits. Tighten the bit securely in the chuck, using the key provided (never tighten the chuck with wrench or pliers). The bit should be set straight and true in the chuck and the work firmly clamped. When drilling metal, the work should be marked with a center punch before beginning the drilling operation.

SOLDERING IRON.—The soldering iron is a fire hazard and a potential source of burns. Always assume that a soldering iron is hot; never rest the iron anywhere but on a metal surface or rack provided for that purpose. Keep the iron holder in the open to minimize the danger of fire from accumulated heat. Do not swing or flip the iron to dispose of excess molten solder—a drop may strike someone, or strike the equipment and cause a short circuit. Keep the head and hands away from the hot end of the iron; hold small soldering jobs with pliers or clamps. Position the ends of wires and cables so that they do not endanger the face or the eyes; never flip the wires to remove excess solder. When cleaning the iron, place the cleaning rag on a suitable surface and wipe the iron across it—do not hold the rag in the hand. Disconnect the iron when leaving the work, even for a short time—the delay may be longer than planned.

GROUNDING.—A poor safety ground, or one that is wired incorrectly, is more dangerous than no ground at all. The poor ground is dangerous because it does not offer full protection, while the user is lulled into a false sense of security. The incorrectly wired ground is a hazard because one of the line wires and the safety ground are transposed, making the shell of the tool "hot" the instant the plug is connected. Thus the unwary user is trapped, unless by pure chance the safety ground is connected to the grounded side of the line on a single-phase grounded system, or no grounds are present on an ungrounded system. In this instance the user again goes blithely along using the tool until he encounters a receptacle which has its wires transposed or a ground appears on the system. Because there is no absolutely foolproof method of insuring that all tools are safely grounded (and because of the tendency of the average sailor to ignore the use of the grounding wire), the old method of using a separate external grounding wire has been discontinued. Instead, a 3-wire, standard, color-coded cord with a polarized plug and a ground pin is required. In this manner, the safety ground is made a part of the connecting cord and plug. Since the polarized plug can be connected only to a mating receptacle, the user has no choice but to use the safety ground.

All new tools, properly connected, use the green wire as the safety ground. This wire is attached to the metal case of the tool at one end and to the polarized grounding pin in the connector at the other end. It normally carries no current, but is used only when the tool insulation fails, in which case it short circuits the electricity around the user to ground and protects him from shock. The green lead must never be mixed with the black or white leads which are the true current-carrying conductors.

Check the resistance of the grounding system with a low reading ohmmeter to be certain that the grounding is adequate (less than 0.1 ohm is acceptable). If the resistance indicates greater than 0.1 ohm, use a separate ground strap.

Some old installations are not equipped with receptacles that will accept the grounding plug. In this event, use one of the following methods:

1. Use an adapter fitting.
2. Use the old type plug and bring the green ground wire out separately.
3. Connect an independent safety ground line.

When using the adapter, be sure to connect the ground lead extension to a good ground. (Do not use the center screw which holds the cover plate on the receptacle). Where the separate safety ground leads are externally connected to a ground, be certain to first connect the ground and then plug in the tool. Likewise, when disconnecting the tool, first remove the line plug and then disconnect the safety ground. The safety ground is always connected first and removed last.

GENERAL HAZARDS

In addition to the specific hazards encountered in electronic maintenance and the obvious dangers involved in falling, tripping, slipping, colliding, etc., the technician is concerned with other general classes of hazards. The following paragraphs, although by no means a complete coverage, will present some pertinent details and general information concerning a few of the most important ones.

FIRE AND EXPLOSION

Although fire and explosion are frequently associated with one another, they may also exist separately. Considerable detail on these subjects is included in Basic Military Requirements, NavPers 10054-B. Study and review of this material will provide a foundation for the specific information presented in this part of this chapter. Information is available in other Navy Training Courses, including the following: Seaman, NavPers 10120-E; Airman, NavPers 10307-C; Military Requirements for Petty Officer 3 & 2, NavPers 10056-B; and Standard First Aid Training Course, NavPers 10081-B.

Fire

A general discussion of the nature of fire, the classes of fires, firefighting systems and equipment, protective clothing and equipment, and fire prevention is contained in chapter 14 of the Rate Training Manual, Basic Military Requirements, NavPers 10054-B. General information concerning aircraft crash rescue and firefighting is found in chapter 15 of Airman, NavPers 10307-C. Specific details relating to firefighting and rescue procedures for a particular model aircraft may be found in the technical manuals published for that model aircraft. Standard First Aid Training Course, NavPers 10081-B, contains general procedures for the rescue of personnel from fire and first aid treatment for fire victims. A thorough study and a review of these references are an obligation of all personnel. Since this material is found in publications which are generally available to naval aviation personnel, it is not presented in detail in this course. However, some details of special interest are summarized in the following paragraphs.

In the case of electrical fires, the following steps should be taken:

1. Deenergize the electrical circuit involved, and any other electrical circuits that may interfere with the proper control or extinguishing of the fire, or which may constitute a hazard to the firefighters.
2. Call the fire department. This should be done even if it is a "small fire" that can be "easily" controlled or extinguished. This is a precautionary measure to be taken in the event of unforeseen complications or miscalculation.
3. Attempt to control or extinguish the fire if possible, using the appropriate fire extinguisher and firefighting procedure.
4. Make a full report on the fire to the appropriate authority. The fire marshal has complete information as to the proper forms and reports, and should be contacted for assistance if needed. However, this does not relieve the person discovering the fire from his responsibility in this matter.

For combating electrical fires, a CO_2 (carbon dioxide) fire extinguisher is best. The carbon dioxide should be directed to the base of the flame, where it will serve two purposes: It cools the area, and it decreases the percentage of oxygen present at the fire. However, for major fires of any type in confined spaces, the excessive use of carbon dioxide may be dangerous, due to the decreasing of oxygen content.

Carbon tetrachloride should not be used for firefighting, because it is converted into phosgene gas (a deadly poisonous gas) upon contact with hot metals. Even in open spaces this gas creates a serious hazard, and the use of carbon tetrachloride is specifically prohibited.

Application of water to electrical fires may be dangerous to personnel and injurious to equipment, because of the electrical conductivity of water and the corrosive properties of water when used on metallic substances.

Foam type fire extinguishers should not be used on electrical fires because the foam is electrically conductive.

Avoid inhaling flames or smoke from fires, as these may cause serious injury or death if breathed to excess.

Special precautions must be taken if the fire is in an enclosed or confined space. Local regulations will detail the appropriate procedure to be followed in this event.

In the case of cable fires in which the inner layers of insulation (or insulation covered by armored or shielded cable) are burning, the only positive method of preventing the fire from running the length of the cable is to cut the cable and separate the ends.

Fumes of an explosive, toxic, or corrosive nature are generated in the combustion of certain substances. This will be discussed in a later portion of this chapter.

Explosion

Explosion may be caused by fire or may be the cause of a fire—or the two may be unrelated. It may be the result of a chemical action, heat, mechanical malfunction, or other causes. An explosion is generally accompanied by a loud noise and a sudden buildup pressure. Several types of explosions are of interest to the technician in the performance of his normal duties.

The accumulation of combustible fumes or vapors from fire or from evaporating liquids represents a potential hazard. A spark or increase in heat from any cause or certain chemical combinations, may trigger the explosion.

An explosion in the presence of fire may result in the rapid spread of that fire. An explosion in the presence of combustible materials may cause a fire to start.

An explosion may result in flying debris which will act as shrapnel and may cause severe personnel injuries. In the event of severe explosion, nearby personnel may suffer from the concussion effect of the blast.

In addition to the fire-caused accumulation of combustible vapors and the accumulation of combustible gases in the vicinity of fire or electric sparking, there are several other explosion hazards. A few of these are discussed in the following paragraphs.

Some equipments are pressurized and are susceptible to explosion in the event of excessive pressurization or mechanical failure of any part of the pressurized system. In this event, the major hazard of the explosion is the creation of shrapnel, or the increased danger of arcing in the absence of the pressurization. Implosion, like explosion, results in creation of shrapnel, frequently with toxic materials coating the splinters. The rapid collapse of glass vacuum tubes is an example of implosion which is of prime importance to electronics personnel.

Explosive ordnance devices are sometimes installed on aircraft or placed adjacent to the aircraft preparatory to loading. Accidental operation of switches may result in the firing of these devices. The technician, when operating any equipment in the aircraft, must keep himself constantly aware of any electrically initiated ordnance devices in the vicinity of his aircraft, and must observe all precautions which apply to the situation. When missiles or weapons are installed, only fully qualified personnel should be permitted to operate any electronic equipment in the aircraft. A definite possibility of detonation of ordnance devices by radiated RF energy is also known to exist. This hazard is discussed later in the chapter under RF radiation hazards.

FUMES

The term FUMES refers to vapors, gases, or smoke, especially those that are strong or dangerous, or which have a potent odor. For purposes of this discussion, fumes may be classified as toxic, explosive, corrosive, poisonous, suffocating, or irritating. They may result from fire, evaporating liquids or solids, chemical action, or overcrowding in confined or poorly ventilated spaces. They may be easily detectable, or almost impossible to detect. They may represent a single hazard, or they may represent a combination of several distinct hazards.

Fuels

The vapors from nearly all hydrocarbon fuels present hazards of fire and explosion as previously discussed; in addition, they are toxic. When breathed in heavy concentration, or for prolonged periods, they may result in permanent damage to the respiratory system, loss of consciousness, paralysis, and/or death. For these reasons, numerous safety regulations and detailed procedures have been issued regarding fuels and fueling operations. In general, the most important of these regulations require rigid enforcement of the NO SMOKING rules, adequate ventilation, restrictions on the use of electrical equipment, use of special equipment, and the presence of manned firefighting equipment.

Painting Supplies and Materials

Most paints and thinners, and many other painting supplies, emit vapors which are both flammable and toxic. Regulations require these items to be stored in closed containers in a noncombustible enclosure isolated from living, working, or ordinary storage spaces. Use of the material is restricted to well-ventilated areas, and in many cases, special equipment and clothing are made available for use.

Battery Fumes

In the standard lead-acid storage battery, explosive fumes are generated by chemical action. In the charging operation, hydrogen is released. Hydrogen is a highly combustible gas, which is violently explosive when in strong concentration. The newer nickle-cadmium batteries do not present this hazard, but do present other hazards as covered in a later discussion. Battery lockers are subject to very strict safety regulations with special emphasis on smoking restrictions and ventilation requirements.

Smoke

Smoke, a byproduct of fire, represents a toxic and suffocating hazard. In addition, there are other fumes frequently present in smoke. These fumes, products of combustion or of increased evaporation, may be poisonous, corrosive, or explosive. It has been previously mentioned that carbon tetrachloride, upon coming into contact with hot metals, is converted into deadly phosgene gas. There are many other materials which are converted by heat or combustion from relatively harmless substances into lethal fumes.

Carbon monoxide is present in nearly all smoke, and is the most common cause of "smoke poisoning" among firefighters and fire victims. Unless the victim is removed from the smoke and administered artificial respiration and/or oxygen, death may result.

The use of gas masks, breathing apparatus, and safety lines is prescribed under certain firefighting situations.

Miscellaneous Materials

Many other general classes of materials contain substances which produce hazardous fumes. These materials should be used only according to specified procedures. Some of these material classes are cleaning materials, insecticides, preservatives, solvents, adhesives, and finishes.

Although not technically classified as fumes, dust and small particles from grinding operations present similar hazards and require precautions similar to those taken for fumes.

CHEMICALS

The subject of chemical warfare (and its agents, treatments, and preventive measures) is treated in detail in Navy Training Manuals for which the prospective PO 3 or 2 is responsible. Among these manuals are Basic Military Requirements, NavPers 10054-B; Military Requirements for Petty Officer 3 & 2, NavPers 10056-B; and Standard First Aid Training Course, NavPers 10081-B.

RADIOACTIVITY

Radioactive materials are in common usage throughout the Navy, and particularly in the electronics field. Common radioactive materials familiar to most technicians include the luminous dials on watches and various instruments, and the luminescent markings on equipment. Radioactive material is intentionally added to many special purpose electron tubes to produce a continuous supply of ionized particles to insure that the tube will always ionize at the same voltage. The principal radioactive materials contained in these tubes include certain isotopes of carbon (C^{14}), cesium (Cs^{137}), cobalt (Co^{60}), nickel (Ni^{63}), and radium (Ra^{226}). These tubes are usually the TR and ATR tubes, glowlamp and cold cathode type tubes, and certain spark gap tubes. With proper precautions and procedures, these materials present no serious hazard; with careless or improper treatment, however, the hazard may become very serious.

Radioactive materials emit rays which may cause changes in living tissue with subsequent injury to the body. The amount of change, and therefore the seriousness of the injury, increases with the amount of radiation absorbed. The absorption of radiation is cumulative, and the repair of damaged tissue is slow; therefore, the hazard level is based on the total amount of radiation absorbed as well as on the rate of absorption.

The primary hazard considered in this discussion is injection of radioactive substances into the bloodstream through a cut or an abrasion, or through penetration of the skin by glass slivers from broken tubes. This type injury may be quite serious, even with minute quantities of radioactive materials injected. The materials injected are carried throughout the body by the bloodstream, and tend to accumulate in certain organs or parts of the body. In addition to the radiation effects, they also cause a type of poisoning similar to chemical poisoning.

A wound caused by a radioactive particle requires treatment by a medical officer as soon as possible, regardless of the size of the wound. The hazard of radioactive particles being left in a wound CANNOT BE IGNORED.

There are no known antidotes for poisoning from radioactive particles which remain in the body. Treatment of radiation sickness is complicated and lengthy. Even with the best medical attention, the results are often inconclusive. However, progress continues in this field and close liaison with the medical department will insure that the latest first aid procedures and medical treatment are used.

Inhalation of minute particles of radioactive dust can cause coating of the mucous membranes, with resultant poisoning and increased radiation effects. Once lodged in the nasal passages or throat, these particles are very difficult to remove—in the lungs they are even more difficult.

Contamination of the skin by radioactive materials may produce radiation burns resembling the temporary redness of a mild sunburn (or in severe cases, a serious flame burn which destroys the skin). All such cases should be reported to the medical authorities immediately; with proper medical care, complete recovery may be expected except in extreme cases involving severe burns over an extensive area. This type injury is rare.

Detection

Radioactive radiation is completely undetectable through use of the human senses; detection relies upon the use of special equipment. The methods of detection and the types of radioactivity detectors are discussed in chapter 15 of the Rate Training Manual, Basic Military Requirements, NavPers 10054-B. Coverage of the subject in this course is limited to a brief discussion of the various conditions and places which require monitoring.

Storage areas containing instruments, equipments, or tubes with radioactive materials should be monitored periodically to insure that the radiation level does not exceed allowable limits. Specifically, the air intake and exhaust screens or filters should be monitored prior to cleaning. All areas surrounding the breakage of any tube containing radioactive material, or the flaking of radioactive paint or markings, should be monitored to help locate all the radioactive material. These areas should be monitored again following decontamination to determine the effectiveness of the procedures used. Personnel should be monitored whenever contact with radioactive materials is suspected, or following participation in decontamination activities.

Precautions

The following safety practices should be observed to minimize the hazard present by radioactive materials:

1. Tubes or instruments should not be removed from cartons until immediately prior to actual installation. This serves two purposes—to prevent accidental breakage, and to avoid the possibility of concentrating several radioactive sources in a small volume (which would increase the effective intensity of radiation).
2. When a radioactive component is removed from equipment, it should be placed in an appropriate carton to prevent possible breakage.
3. Items containing radioactive materials should never be carried in a pocket or elsewhere about the person in a manner that flaking or breakage can occur.
4. Extreme care should be exercised in the handling of these items while installing or removing them from equipment.
5. Tubes should never be broken intentionally; however, if breakage does occur, material contaminated by radioactivity should not be allowed to come in contact with any part of the body at any time. Take care to avoid breathing any dust or vapor (such as radon gas, a highly radioactive substance) which may be released by such breakage. Immediately locate all broken pieces, and isolate the area until the broken pieces have been removed or declared nonradioactive by test with an adequate radiation-sensitive device.
6. No food or drink should be brought into the contaminated area or near any radioactive material.
7. Immediately after leaving a contaminated area, personnel who have handled radioactive material in any way should remove contaminated clothing. They should wash their hands and arms thoroughly with soap and water, especially before eating, drinking, or smoking.
8. When a wound caused by a sharp radioactive object is sustained, report to medical authorities for treatment as soon as possible.

Decontamination and Disposal

When cleaning a contaminated area, rubber or plastic gloves should be worn. Large fragments of a broken tube should be removed with the aid of some tool such as forceps, if they are available. The remaining particles can be removed with a vacuum cleaner, using a disposable collecting bag, or by wiping a wet cloth across the area. (If the breaking of tubes is a frequent occurrence, care should be given to selecting the best type of collecting bags.)

If a wet cloth is used, make one stroke at a time, and fold the cloth in half after each stroke, always using a clean side. When the cloth becomes too small, discard it and continue with a clean piece. Be careful not to rub the radioactive particles into the surface by using a back-and-forth motion. All debris, cloths, and bags used for cleaning should be sealed in a container such as a plastic bag, heavy waxed paper, or a glass jar, and placed in a steel can for disposal.

Radioactive waste materials and sweeper bags should not be disposed of individually. They should be collected in a designated steel container with a tight-fitting lid and suitable marking until a reasonable quantity for disposal has been gathered. Containers for radioactive materials should be marked with the radiation symbol. (See fig. 3-1.) The symbol is printed in magenta (purplish shade of red) color on a yellow background.

Radioactive waste can be disposed of by burying in soil or by sinking in the ocean. Detailed information concerning the disposal of radioactive materials is contained in BuShips Instruction 5100.15.

ELECTRICAL HAZARDS

Every person who works with electronic equipment should be constantly alert to the hazards of the equipment to which he may be exposed, and also be capable of rendering first aid to injured personnel. The installation, operation, and maintenance of electronic equipment requires enforcement of a stern safety code. Carelessness on the part of the operator or the maintenance technician can result in serious injury or death due to electric shock, falls, burns, flying objects, etc. After an accident has happened, investigation almost invariably shows that it could have been prevented by the exercising of simple safety precautions and procedures with which the personnel should have been familiar.

Each man concerned with electronic equipment should make it his personal responsibility to read and become thoroughly familiar with the safety practices and procedures contained in applicable safety directives, manuals, and other publications, and in equipment technical manuals prior to performing work on electronic equipment. It is the individual's responsibility to identify and eliminate unsafe conditions and unsafe acts which cause accidents.

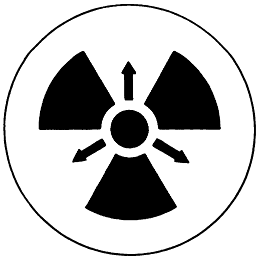

AT.13

Figure 3-1.—Radiation symbol.

INJURIES FROM ELECTRICITY

Damage to the body may be caused by the passage of electric current over the skin or through the body. In any case, it is important to remember that it is the current, not the voltage, that causes the damage. This current, if of sufficient magnitude, may cause asphyxiation, burns, and/or shock. Because individuals differ in susceptibility to electrical shock and its associated hazards, exact figures are hard to determine.

However, the current magnitude resulting from application of any voltage varies inversely with resistance. When dry, the body has a comparatively high resistance. When moist, however, body resistance is greatly reduced. Even "low voltage" can be extremely hazardous under conditions of heavy perspiration or damp surroundings.

Symptoms of electric shock, and procedures for rescue of electric shock victims are discussed in Standard First Aid Training Course, NavPers 10081-B. Since this topic is of such great importance to all personnel involved in electronics, that material should be studied with great care.

GENERAL PRECAUTIONS

Take time to be safe when working on electronic circuits and equipment. Carefully study the schematics and wiring diagrams of the entire system, noting what circuits must be deenergized in addition to the main power supply. Remember that electronic equipments frequently have more than one source of power. Be certain that ALL power sources are deenergized before servicing the equipment. Do not service any equipment with the power on unless it is necessary.

It must be borne in mind that deenergizing main supply circuits by opening supply switches will not necessarily "kill" all circuits in a given piece of equipment. A source of danger that has often been neglected or ignored—sometimes with tragic results—is the inputs to electronic equipment from other sources, such as synchros, remote control circuits, etc. For example, turning off the antenna safety switches will disable the antenna, but it may not turn off the antenna synchro voltages from other sources. Moreover, the rescue of a victim shocked by the power input from a remote source is often hampered because of the time required to determine the source of power and turn it off. Therefore, turn off ALL power inputs before working on equipment.

Remember that the 115-volt power supply voltage is not low, relatively harmless voltage, but is the voltage that has caused more deaths in the Navy than any other.

Do NOT work with high voltage circuits by yourself; have another person (safety observer), who is qualified in first aid for electrical shock, present at all times. The man stationed nearby should also know the circuits and switches controlling the equipment, and should be given instructions to pull the switch immediately if anything unforeseen happens.

Always be aware of the nearness of high voltage lines or circuits. Use rubber gloves where applicable, and stand on approved rubber matting (MIL-M-15562). Not all so-called rubber mats are good insulators.

Equipment containing metal parts, such as brushes and brooms, should not be used in an area within 4 feet of high voltage circuits or any electric wiring having exposed surfaces.

Inform remote stations as to the circuit on which work is being performed.

Keep clothing, hands, and feet dry if at all possible. When it is necessary to work in wet or damp locations, use a dry platform or wooden stool to sit or stand on, and place a rubber mat or other nonconductive material on top of the wood. Use insulated tools and insulated flashlights of the molded type when required to work on exposed parts.

Do not wear loose or flapping clothing. The use of thin-soled shoes with metal plates or hobnails is prohibited. Safety shoes with nonconducting soles should be worn if available. Flammable articles, such as celluloid cap visors, should not be worn.

When working on electronic or electrical apparatus, technicians should first remove all rings, wristwatches, bracelets, ID chains and tags, and similar metal items. Care should be taken that the clothing does not contain exposed zippers, metal buttons, or any type of metal fastener.

Do NOT work on energized circuits unless absolutely necessary. Be sure to take time to lock out (or block out) the switch and tag it. Locks for this purpose should be readily available; if a lock cannot be obtained, remove the fuse and tag it.

Use one hand when turning switches on or off. Keep the doors to switch and fuse boxes closed except when working inside or replacing fuses. Use a fuse puller to remove cartridge fuses after first making certain that the circuit is dead.

All supply switches or cutout switches from which power could possibly be fed should be secured in the OPEN (safety) position and tagged. The tag should read "THIS CIRCUIT WAS ORDERED OPEN FOR REPAIRS AND SHALL NOT BE CLOSED EXCEPT BY DIRECT ORDER OF ________" (the person making, or directly in charge of, repairs).

Never short out, tamper with, or block open an interlock switch. Keep clear of exposed equipment; when it is necessary to work on it, use one hand only as much as possible.

Warning signs and suitable guards should be provided to prevent personnel from coming into accidental contact with high voltages.

Avoid reaching into enclosures except when absolutely necessary; when reaching into an enclosure, use rubber blankets to prevent accidental contact with the enclosure.

Do not use bare hands to remove hot tubes from their sockets. Use asbestos gloves or a tube puller.

Use a shorting stick, similar to the one shown in figure 3-2, to discharge all high voltage charges. Before a worker touches a capacitor or any part of a circuit which is known or likely to be connected to a capacitor (whether the circuit is deenergized or disconnected entirely), he should short circuit the terminals to make sure that the capacitor is completely discharged. Grounded shorting sticks should be permanently attached to workbenches where radar equipment and other types of electronic devices using high voltages are regularly serviced.

Make certain that the equipment is properly grounded. Ground all test equipment to the equipment under test.

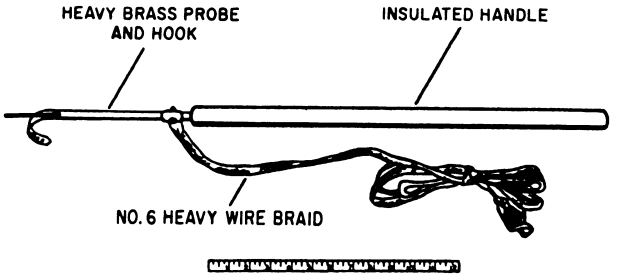


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Figure 3-2.—Shorting stick.

Turn off the power before connecting alligator clips to any circuit.

When measuring circuits over 300 volts, do not hold the test prods.

Transmitter adjustments should not be made while the equipment is energized unless the adjustments can be accomplished from the front control panel. Similar precautions should be taken with oscilloscope circuits, which employ voltages comparable to those used in transmitting equipment.

Avoid exposure to high concentration of RF radiation. When operating high power RF transmitters or radar equipment, make sure that the beam is not directed at personnel, fuel, or ordnance areas. Hazards involved in RF radiation are discussed in a later section of this chapter.

Use only rubber or insulating hose on airlines for blowing out equipment. Use no more than 10 pounds of pressure to avoid damage to the insulation and injury to personnel. Be sure the air is free from water. Never turn compressed air on yourself or others, since it can cause serious injury.

DEGREE OF SHOCK

The amount of current that may pass through the body without danger depends on the individual and the current quantity, the type, path, and length of contact time.

Body resistance varies from 1,000 to 500,000 ohms for unbroken, dry skin. Resistance is lowered by moisture and is highest with dry skin. Breaks, cuts, or burns may lower body resistance to 200 ohms. A current of 1 milliampere can be felt and will cause a person to avoid it. Five milliamperes is about the highest current safe for the average body. If the palm of the hand makes contact with the conductor, a current of about 12 milliamperes will tend to cause the hand muscles to contract, freezing the body to the conductor. Such a shock may or may not cause serious damage, depending on the contact time and your physical condition, particularly the condition of your heart. A current of only 25 milliamperes has been known to be fatal.

Generally, currents between 100 and 200 milliamperes are lethal. Ventricular fibrillation of the heart occurs when the current through the body approaches 100 milliamperes. Ventricular fibrillation is the uncoordinated actions of the walls of the heart's ventricles. This in turn causes the loss of the pumping action of the heart. Fibrillation is difficult to stop by ordinary means; therefore, it is usually fatal.

If currents of 200 milliamperes or higher pass through the body severe burns and unconsciousness result. Generally, in these cases the heart will not fibrillate but will be stopped. The victim will usually respond if by some means the heart is caused to start again. The heart may respond if resuscitation in the form of artificial respiration is given to the victim.

When a person is rendered unconscious by a current passing through the body, it is impossible to tell how much current caused the unconsciousness. Artificial respiration must be applied immediately if breathing has stopped and continued until otherwise directed by medical authority.

SPECIAL COMPONENTS

In addition to the general hazards and precautions listed previously, several components common to aviation electronic maintenance present hazards or potential hazards. The following paragraphs present a brief summary of some of the more important of these components and their hazards.

Selenium Rectifiers

When selenium rectifiers burn out, fumes of selenium dioxide are liberated, causing an overpowering stench. The fumes are poisonous and should not be breathed. If a rectifier burns out, deenergize the equipment immediately and ventilate the compartment. Allow the damaged rectifier to cool before attempting any repairs. If possible, move the equipment containing it out of doors. Do not touch or handle the defective rectifier while it is hot, since a skin burn might result, permitting some of the selenium compound to be absorbed.

Batteries

Battery hazards are most common during the charging process and during the installation and removal process. The weight and clumsiness of the battery contribue to the strain hazard; commonsense and routine attention to detail minimize this hazard. All rechargeable storage batteries should be charged in strict accordance with the manufacturer's recommendations.

LEAD-ACID.–Lead-acid storage batteries present hazards of acid burn, explosion, and strain. Burns may be prevented by the proper use of eyeshields, rubber gloves, rubber aprons, and rubber boots with nonslip soles. This protective clothing should be worn whenever refilling, checking, transporting, or charging batteries. Explosion may result from accumulation of hydrogen gas during charging operation. Proper ventilation and strict enforcement of the no smoking rules are mandatory.

NICKEL-CADMIUM.–The electrolyte used in nickel-cadmium (NiCad) batteries is potassium hydroxide (KOH), a highly corrosive alkaline solution which should be handled with the same degree of caution as sulfuric acid. If KOH is sprayed on any material, wash it immediately with liberal quantities of water and neutralize the affected area with vinegar or a weak solution of acetic acid.

An extremely violent explosion would occur if KOH were added to a lead-acid battery or if sulfuric acid were added to a NiCad battery. Although there is no valid excuse for such an occurrence, inattention to detail can make it possible. All battery electrolytes should be kept in clearly marked containers and should, if possible, be kept in different storage areas when not in use.

MERCURY CELL.–Under certain conditions, mercury dry cells or batteries may explode. The most common cause of explosion is overloading the battery (with the subsequent heating and ignition of hydrogen gas within the cell). The loading capacity of the battery is decreased as the battery is discharged. When a mercury cell (or any cell within a mercury battery) has discharged to 70 percent of its nominal voltage, the cell or battery should be replaced. Discharged mercury batteries should never be stored; holes should be punched in the steel jacket and the battery discarded.

Cathode-Ray Tubes

Extreme caution should be exercised in handling a cathode-ray tube (CRT). The glass envelope encloses a high vacuum; and because of the large surface area, the envelope is subjected to considerable total force due to atmospheric pressure. (See chapter 5 of this manual for a discussion of total force and pressure.)

The trend toward the use of larger CRT's has increased the hazard of IMPLOSION (collapse of the glass tubes as a result of atmospheric pressure). The tubes are not considered hazardous if handled properly; but if they are struck, scratched, dropped, or handled improperly in any way, they may become an instrument of severe injury or death.

When handling, installing, or removing a CRT, use extreme care to avoid contact between the tube and any sharp or hard object. Wear suitable gloves to protect [illegible]ds. Wear goggles to protect the e[illegible] glass particles in the event of [illegible] goggles should provide both s[illegible] protection, and should have clea[illegible] can withstand a rigid impact. Ins[illegible] carefully into the socket, using on[illegible] pressure. Do not jiggle the tube. [illegible] it by the narrow neck. Do not sta[illegible] directly in front of the face of the tube; accidental implosion may cause the electron gun or other parts to be propelled directly forward with sufficient velocity to cause severe injury. When the tube must be set down, it is important that the face be placed gently on a thick, clean, soft padding.

In addition to the hazard of implosion, rough handling may also result in displacement of the electrodes within the tube and result in faulty operation or nonoperation of the tube.

The chemical coating material on the face of the tube may be extremely toxic. When disposing of a broken tube, use protective devices and procedures to insure that none of this compound gets on the hands or into the skin.

Before a CRT is discarded, the danger of implosion must be eliminated. Place the defective tube face down in an empty CRT carton, carefully break off the locating pin from the tube base, and (using a small screwdriver, pliers, or a probe) break off the tip of the glass vacuum seal. (See fig. 3-3.) With the vacuum seal broken, pressure inside and outside the tube becomes equalized, and the danger of implosion is removed. However, all other hazards still remain.

Dielectric Materials

The increasing use of microwave energy and the accompanying increase in power levels have given rise to several significant problems. Among the problems which have arisen are those resulting from the use of certain dielectric materials in new environments without previous application experience. In several cases situations have developed in which personnel were exposed to potentially toxic agents as a direct result of the introduction of new substances about which little toxicological information was available.

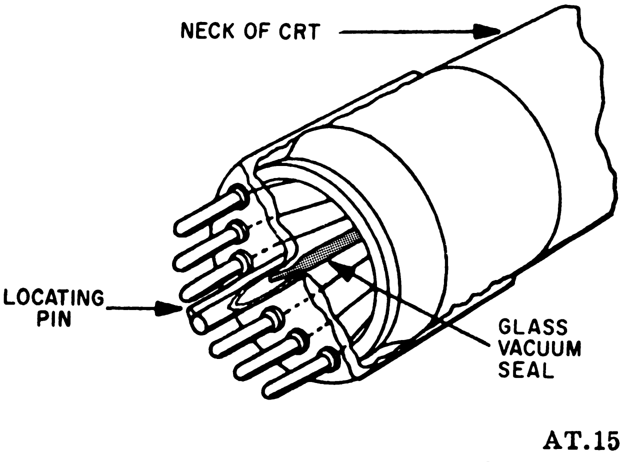


Figure 3-3.— Constuction of cathode-ray tube base.

One example is the use of sulfur hexafluoride (SF4) as a gas dielectric to increase power handling capability of waveguides. In its pure state, this gas is essentially inert and nontoxic. However, when arc-over occurs in a waveguide filled with the gas, decomposition products constitute a toxic gas hazard. These toxic gases, which include fluorine, may not irritate the skin, are colorless, and cannot be detected by odor. However, they may cause extreme lung irritation and hemorrhaging.

Arcing may take place periodically in the waveguide until the system fails completely, or at least until system performance drops below an acceptable minimum level. If a maintenance technician should open the waveguide while effecting repairs on the system, he may release these highly toxic agents.

When opening a waveguide pressurized with sulfur hexafluoride, personnel, should use approved respiratory protective devices. All such work should be accomplished in a well-ventilated space, and the area should be cleared of all toxic hazard before allowing other personnel to enter the area.

As toxicological or other information regarding safety matters becomes available, precautionary measures and protective devices are developed, distributed, and promulgated. Until it has been ascertained that a new material or substance is completely safe, precautionary measures should be used as if definite hazards were known to exist.

RF RADIATION

Electromagnetic radiation is not visible; its presence must be detected and measured by instruments or approximated by theoretical calculations. Radiated beams of high power RF energy present a health and safety hazard. In general, health and safety factors fall into the ordnance, personnel, fuel, and miscellaneous aspects. The establishment of health and safety precautions regarding electromagnetic radiation is a joint responsibility of the Bureau of Medicine and Surgery, the Naval Air Systems Command, and the Naval Ship Systems Command. Publications which may prove valuable for further reference include Radio-Frequency Hazards Manual, NavOrd OP 3565 (a Confidential manual), and Electronics Installation and Maintenance Book - Test Methods and Practices, NavShips 100,000.103.

The energy striking an object in an electromagnetic field may be reflected, transmitted, or absorbed; only the absorbed energy constitutes a hazard. The hazard resulting from focused concentration of such energy, like any hazard, can be rendered relatively harmless by understanding and precaution.

ORDNANCE HAZARDS

The hazards of electromagnetic radiation to ordnance (HERO) problem has become acute. The number and variety of electrically initiated explosive devices are increasing rapidly. For example, some currently operational weapons contain more than 75 electroexplosive devices. Continuing development efforts are directed toward reducing weight and space requirements, lowering power requirements, assuring positive response, and increasing safety and reliability. However, these goals are not always complementary.

At the same time, the power of communications and radar transmitting equipment is constantly being increased and the frequency spectrum broadened. The radiofrequency spectrum now used by the airborne Navy extends from 10 kHz to about 20,000 MHz. Transmitter power outputs extend to 10 kw at communications frequencies, and peak power outputs extend to approximately 5 megawatts at radar frequencies.

These trends produce situations which are in direct conflict with each other. On the one hand, transmitters and their antennas have only one purpose–to radiate electromagnetic energy. The initiating elements of ordnance devices need only to be supplied with the proper amount of electrical energy for an explosion to take place. Therefore, with many explosive ordnance items, certain precautions are required for safety and to insure reliable performance.

To meet the growing need for new procedures to reduce the hazard to ordnance equipment from RF radiation, the Naval Air Systems Command has sponsored tests which, coordinated with studies made by other agencies, have provided new guidelines and restrictions for handling electrically initiated ordnance equipment.

The basic problem in determining an ordnance system's susceptibility to RF radiation lies in the evaluation of the antennalike couplings that exist between illuminating fields and the electroexplosive devices in the system. RF energy may enter a weapon as a wave radiated through a hole or crack in the weapon skin, or it may be conducted into the weapon by the firing leads or other wires leading into the weapon.

The exact chances of electroexplosive device firing are quite unpredictable, being dependent upon such variables as frequency, field strength, positional and directional orientation, environment, and metallic or personnel contacts with the ordnance or aircraft.

The most susceptible period is during assembly, disassembly, loading, unloading, or testing in electromagnetic fields. The most likely effects of premature actuation are dudding, reduction of the reliability of the device, or propellant ignition. In extreme cases, there is a definite possibility of warhead detonation.

Some specific safety precautions which the technician must observe with respect to these weapons and ordnance devices include the following:

1. Turn off all RF transmitters during weapon handling operations in the area.
2. Observe all local and general safety and HERO restrictions.
3. Maintain radio and radar silence during assembly, disassembly, loading, unloading, or testing operations.
4. Avoid illumination of ordnance devices by high power RF transmitters.

The HERO problem is a complex one. The hazard, and therefore the solution, is a function not only of frequency and field strength, but also of geometrical configuration, orientation, and the antenna characteristics of the weapon or weapon-aircraft and weapon-launcher combinations. In general, the path by which energy is introduced to the electroexplosive devices is not readily defineable.

Development projects are underway in several areas to provide special devices and material which will have general application as HERO remedies. It is expected that some of these devices, and some developed by other agencies, will be valuable in the design of new weapons as well as modifications for existing weapons. Many possibilities have been and are being explored. These include shielding, filters, RF dissipating attenuators, less sensitive electroexplosive devices, exploding wires, conductive film igniters, spark gap primers, inductive firing devices, and modifications to aircraft armament circuits.

PERSONNEL HAZARDS

Development of RF systems with high power transmitting tubes and high gain antennas has increased the hazard to personnel in the vicinity of these elements. Harmful effects of overexposure to RF radiation are associated with the average power of the absorbed radiation. They are thermal in nature, and are observed as an increase in overall body temperature or as a temperature rise in certain sensitive organs of the body. The only known nonthermal effects on personnel are due to power density values considerably greater than the power densities normally associated with present RF transmitting systems.

The Bureau of Medicine and Surgery has established safe limits based on the power density of the radiation beam and the exposure time of the human body in the radiation field. All areas in which the RF levels exceed the safe limits are considered hazardous. The Naval Ship Systems Command is responsible for determining hazardous shipboard areas and for decreasing the hazard to personnel from RF radiation. Theoretical calculations and power density measurements are used to establish the distances from radar antennas within which it is not biologically safe for personnel to enter. This information is then used to determine if and where hazardous areas exist. All hazardous areas subject to entry by personnel are posted with warning signs, and the ship's intercommunication system is used to warn personnel when the radars are operating.

Personnel Safety Precautions

While every effort must be made to protect personnel from harmful exposure to RF radiation, it is not considered necessary or desirable, in general, that blanket restrictions on antenna radiation be imposed to achieve this end. The existence of such a policy would tend to restrict maintenance and checkout procedures which could otherwise be carried out in safety, provided proper precautions are taken to keep personnel clear of hazardous intensity levels. These precautions include the following:

1. Visual inspection of feed horns, open ends of waveguides, and openings emitting RF electromagnetic energy must not be made unless the equipment is definitely secured for the purpose of such an inspection.
2. Aircraft employing high power radar should be parked, or their antennas should be oriented, so that the beam is directed away from personnel working areas.
3. All personnel must observe RF hazard warning signs which point out the existence of RF radiation hazards in a specific location or area.
4. Those radar antennas which normally rotate are to be rotated continuously while radiating, or trained to a known safe bearing.
5. Nonrotating antennas must be trained and elevated away from inhabited areas, hangars, shop spaces, ships, piers, etc., while radiating.
6. Where a possibility of accidental overexposure might still exist, have a man stationed within view of the antenna (but well out of the beam and in communication with the operator while the antenna is radiating) to warn personnel of the hazard.
7. Radiation hazard warning signs should be available and must be used, not only where they are required to be permanently posted, but also where they may temporarily restrict access to hazardous areas.

FUEL HAZARDS

The increase in radiated RF energy from higher powered communications and radar equipments in recent years has increased the pontential hazard of RF-induced ignition of volatile fuel-air mixtures. This flammable condition is normally present only close to aircraft fuel vents, open fuel inlets, or spilled fuel, or during over-the-wing fueling operations. Ignition of fuel vapors in air has actually occurred; however, the probability of ignition with normal refueling conditions is remote.

Ignition of gasoline vapors caused by RF-induced arcs is rare because ALL the following conditions must exist:

1. A flammable fuel-air mixture must be present within the range of the induced arcing.
2. The arc must contain a sufficient amount of energy to cause ignition.
3. The gap across which the arc occurs must be a certain minimum distance, and must contain a sufficient amount of the flammable mixture to ignite. The possibility of these conditions occurring simultaneously is probably statistically remote; but since the possibility does exist, care must be exercised.

MISCELLANEOUS ASPECTS

The firing of photoflash bulbs, fluorescent lamps, and neon glowlamps by electromagnetic energy from radar sets is a fairly well known phenomenon. Although this type occurrence is normally of little consequence, burns can result. Photographic personnel should be warned of the presence of any high power radar operating in the area and of the hazards involved.

In a similar manner, steel wool may be set afire, or metallic chips may produce sparks when exposed to radiation. With some high power radar sets, steel wool is ignited with a violent explosion. The presence of oil and spilled fuels in the vicinity of aircraft constitutes a serious hazard. This makes good housekeeping procedures essential.

PERSONNEL INJURIES AND SAFETY EDUCATION

The primary purpose of any safety education program is the PREVENTION of personnel injuries or material damage. For any safety program to be effective, all personnel must be aware of the potential hazards present, and they must observe all necessary precautions at all times. This part of the overall safety education program may be best directed by specially qualified personnel in each aspect of safety, or by a safety engineer if one is available.

A second, but vital, aspect of the safety education program is FIRST AID. This part of the program is usually under the direction of Medical Department personnel.

Since a complete training course of this type is quite time consuming, the most immediate requirement is to instill into all personnel a constant awareness of their actions and their surroundings. This awareness, and commonsense, are absolute essentials—without them no safety education program can be effective. The instilling and maintaining of these characteristics is best promoted by coworker and immediate supervisory personnel.

CHAPTER 4

PUBLICATIONS, DRAWINGS, AND SCHEMATICS

At the beginning of World War II, the field of airborne electronics was still quite small. With a little study and some experience, the technician could become quite familiar with all the electronics equipment in the type aircraft employed or supported by his unit. The equipments were comparatively simple, similar in operation and physically large enough for ease of inspection and repair. It was possible for the technician to service, maintain, and repair this equipment with perhaps only an occasional reference to a manual or a schematic.

In the present state of the art, however, this practice is no longer possible. Even a mere listing of the electronics equipment carried on some of the more modern aircraft would be quite lengthy. It is impossible for any one person to be thoroughly familiar with all the various types of electronics equipment in present use; but with a good general background of electronic principles and circuit theory, a little study will enable the technician to rapidly familiarize himself with any specific equipment.

The purpose of this chapter is to discuss some of the sources of information available to the technician, how to use these references, and how to locate details on items of information the technician needs in the performance of his duties. Included in this chapter are discussions of publications, both general and specific; drawings and schematics, including illustrations, block diagrams, and wiring and cabling diagrams; charts and tables; and a brief coverage of procedures for the handling of classified materials and information.

PUBLICATIONS

Naval publications are important sources of information for guiding personnel of the naval aeronautic organization. Generally, these publications fall into two broad groups—those dealing with operational and administrative matters, and those dealing with technical and material matters.

The Secretary of Defense approved a reorganization of the Department of the Navy, which was effective 1 May 1966. This reorganization increases the breadth of authority and responsibility of the Chief of Naval Operations under the continuing direction of the Secretary of the Navy.

The Chief of Naval Operations has three major commands under him—BuPers, BuMed, and Chief of Naval Material.

The Chief of Naval Material heads the Naval Material Command which consists of the following six commands:

1. Naval Air Systems Command.
2. Naval Electronic Systems Command.
3. Naval Ship Systems Command.
4. Naval Ordnance Systems Command.
5. Naval Supply Systems Command.
6. Naval Facilities Engineering Command.

Each of the above commands is headed by a Commander; i.e., Commander, Naval Air Systems Command.

Concurrent with the establishment of the Naval Material Command, the following office and bureaus were abolished:

1. Office of Chief of Naval Material.
2. Bureau of Naval Weapons.
3. Bureau of Ships.
4. Bureau of Supplies and Accounts.
5. Bureau of Yards and Docks.

For example, the Naval Air Systems Command is issuing its own directives and incorporating into its directives pertinent material now in BuWeps directives. Therefore, BuWeps directives and instructions will continue to be used and referred to in training courses for sometime to come even though the Bureau of Naval Weapons has been replaced by the Naval Air Systems Command.

Publications dealing primarily with the operation and maintenance of aircraft and related equipment within the Naval Establishment originating from the Naval Air Systems Command are issued by authority of the Commander, Naval Air Systems Command.

Publications concerned mainly with the training of flight personnel and air operations emanate from the Office of the Deputy Chief of Naval Operations (AIR).

The Naval Air Technical Services Facility functions as the sponsor of both types of publications and controls the initial distribution, distribution lists, printing, and retention of reproducible copy.

The Forms and Publications Supply Office functions as inventory manager for residual stocks of both types of publications, including the supporting distribution system and numerical cataloging.

The basic sources of technical aeronautic information are the technical manuals (formerly called handbooks) issued by the Naval Air Systems Command. Letter publications usually supplement the information contained in aeronautic technical manuals.

Technicians at the E-4 and E-5 levels are primarily concerned with technical publications; therefore, this discussion is directed mainly toward them. However, it includes some coverage of general and administrative type publications of importance to all naval personnel.

Good technical manuals are vital to the maintenance of modern weapons systems. Our Navy's combat readiness depends, to an increasing degree, on the information and knowledge possessed by maintenance personnel. If these men are to maintain increasingly complex weapons systems, incorporating the latest devices and systems, they must be able to obtain the required information from technical manuals.

The Department of Defense, the Department of the Navy, and the Naval Air Systems Command are working together to improve the standardization and quality of aeronautic maintenance manuals. The purpose of the following discussion is to present some detailed information concerning the contents and uses of these manuals.

PUBLICATIONS LISTS

Aeronautic publications originated by the Naval Air Systems Command and distributed by the Naval Air Technical Services Facility are covered by separate lists and indexes as listed below:

1. Navy Stock List of Forms and Publications, NavSup Publication 2002, Cognizance Symbol I, Section VIII, Part C. This stock list contains a numerical listing by code numbers and latest issue date of available aeronautic technical manual type publications. The date indicates the date of the basic book, latest change, or revision.
2. Navy Stock List of Forms and Publications, NavSup Publication 2002, Cognizance Symbol I, Section VIII, Part D. This stock list contains a listing of latest issue dates of aeronautic letter type publications.

NOTE: These stock lists are prepared by the Forms and Publications Supply Office, Byron, Georgia, and distributed to the mailing list maintained by the Naval Air Technical Services Facility, 700 Robbins Avenue, Philadelphia, Pa., 19111.

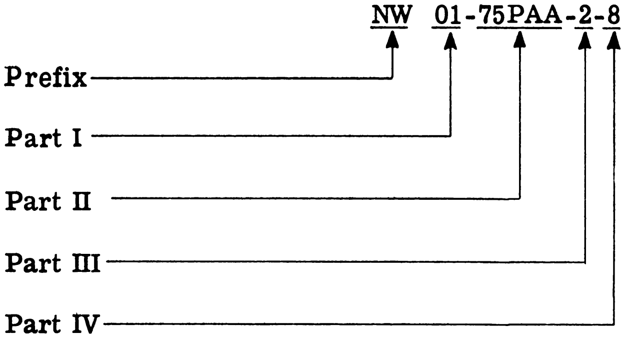
3. The Naval Aeronautic Publications Index, NavAir 00-500 (Series), is prepared in three volumes. It is prepared and distributed by the Naval Air Technical Services Facility. Parts A and B are issued in March and September, with supplements quarterly; Part C is issued in July and January, with no supplements.

The Equipment Applicability List, NavAir 00-500A, lists aircraft components and related equipment by model, type, and part number in alphabetical and numerical sequence with the applicable publications shown in appropriate columns. The Aircraft Application List, NavAir 00-500B, lists aeronautic manual publications with respect to their application to specific aircraft. It lists technical manuals dealing with electronics, armament, instruments, accessories, powerplants, aircraft, and certain general publications. It does not list letter type publications. The Directives Application List, NavAir 00-500C, lists active letter type publications and technical directives with respect to their applicability to specific aircraft.

NUMBERING SYSTEM FOR MANUALS

Publications issued by the Naval Air Systems Command are designated according to a numbering system based on the type publication and its material content. The system cannot be described fully in this course because of its complex nature and many exceptions.

Coded designations assigned to technical manuals consist of a prefix and an alphanumeric sequence of three or four parts. The example shown below will be used to explain the system for designation of technical manuals:



Prefix

The prefix may consist of the letters NavAir (NA), NavAer (NA), NavWeps (NW), AN, TO, or CO. NavAer and NavWeps publications were issued by the Bureau of Aeronautics and Bureau of Naval Weapons, respectively. All new publications are designated with the NavAir (NA) prefix.

The prefix AN was previously assigned for technical manuals used jointly by the Navy and the Air Force; they were prepared to coordinate military specifications.

TO was the prefix assigned to technical manuals originated by the Air Force.

CO was previously used to designate a technical manual with a Confidential security classification.

These prefixes, while no longer assigned for new material, will remain in effect for existing assignments until superseded.

Part I

Part I consists of numbers to identify the general subject classification with the basic subject to which they pertain. These numbers usually have two digits; however, when an additional classification breakdown is necessary, Part I consists of two digits followed by a letter. An example of this is found in the 02 (Powerplants) series. A typical entry in this series has the number 02B immediately following the prefix NW. In this example, the B identifies the powerplant as a jet propulsion type.

Table 4-1 lists the general subject categories and their numerical equivalent. In some instances, it will be noted that an equipment category has more than one numerical equivalent. In the case of electronics, which carries the codes 08 and 16, the equipment category is in the process of subdivision or change.

Part II

Part II of the publication number consists of numbers (or numbers and letters) and indicates the specific class, group, type, or model and manufacturer of the equipment. The subject breakdowns are listed at the beginning of each separate major division within NavSup Publication 2002, Cognizance Symbol I, Section VIII, Part C.

For aircraft manuals and equipment manuals, this part will be explained in more detail later.

Part III

Part III consists of a number or numbers which designate a specific manual. For airframes and engines, this part designates a specific type manual. For other types of equipment, this part is assigned in numerical sequence and has no direct reference to the type of manual.

Part IV

Part IV pertains only to certain specific classes of manuals (such as the Maintenance Instructions Manuals for aircraft), and designates a particular manual of a set. Numbering is not completely standardized, and may have decimal or even double decimal suffixes. The exact volume desired may be determined from the lists or indexes of publications.

Table 4-1. —Subject categories and code numbers for aeronautic manuals.

General	00
Allowance lists	00-35Q
Training publications (aviation)	00-80
Aircraft	01
Powerplants	02
Accessories	03
Hardware and rubber	04
Instruments	05
Fuels, lubricants, and gases	06
Dopes and paints	07
Ground servicing and automotive equipment	08-20, 14 & 19
Photography	10
Armament	11
Fuel and oil handling equipment	12
Parachute and personal equipment	13
Standard preservation and packaging instructions	15
Electronics	08 & 16
Machinery, tools, and test equipment	17 & 18
Descriptive data for aviation support equipment	20
Chemical equipment	24 & 39
Instructional equipment and training aids	09 & 28
Meteorology (aerology)	50
Ships installations	51

AIRCRAFT MANUALS

Aircraft manuals are prepared by the manufacturer and published for each aircraft model in naval use. The manual for a particular aircraft model consists of a series of individual publications, each dealing with a definite phase of the overall operation or maintenance program. As indicated in the preceding discussion, aircraft manuals fall into the 01 - series category, and manuals pertaining to a particular model may be identified by an alphanumeric designator immediately following the 01 -.

01 - Series Manuals

Aircraft technical manuals are of several different types, some of which are of extreme importance to the maintenance technician in the routine performance of his normal duties. These types are discussed in some detail in this chapter. Manuals of some other types are of limited importance to avionics personnel, and are discussed only briefly.

Using the previous example of manual designation, the aircraft model to which a manual applies may be determined from Part II of the designator. The numbers are coded to indicate the specific manufacturer, and the letters indicate the particular aircraft model.

GENERAL AIRCRAFT MANUALS.–The 01-1 series manuals do not apply to specific aircraft, but present some aspect of construction, operation, maintenance, repair, or inspection applicable to many models of aircraft. Some important examples of this type manual are NavAer 01-1A-505 (Installation Practices: Aircraft Electric and Electronics Wiring); NavWeps 01-1A-509 (Handbook Aircraft Maintenance Cleaning); and NavWeps 01-1A-509 (Handbook Corrosion Control for aircraft).

FLIGHT MANUALS.–Manuals of this class are identified by the number 1 in Part III of the standard nomenclature. For a given model aircraft, the complete flight manual usually comprises the standard NATOPS manual, pocket checklist, and classified supplements. Although this series is of primary interest to the pilot and aircrew, much of the information is of general interest to all personnel concerned in any manner with that aircraft. One section of special interest to avionics personnel is the functional operation of the electronics equipment installed.

STRUCTURAL REPAIR.–Structural Repair Manuals (identified by the number 3 in Part III of the standard nomenclature) usually comprise two manuals. The -3-1 manual is for use by organizational and intermediate level maintenance activities, while the -3-2 manual is for use by depot level maintenance activities. These manuals prescribe procedures and methods for making repairs to structural components of the aircraft.

MISCELLANEOUS MANUALS.–Although the contents of most other aircraft manuals are standardized, the numbering system is not. Some typical examples are the Special Weapons Check List, Special Stores, Assembly Procedures (for guided missile and target aircraft), Source Coded Data, Component and Shop Repair Data, etc. Some aircraft have only a few manuals of this type; others have many.

Maintenance Instructions Manual (MIM)

For this type manual, Part III of the standard designator is the number 2. The MIM comprises a variable number of individual publications, each dealing with some portion of the overall maintenance effort for the applicable model aircraft. The MIM (formerly called Handbooks of Maintenance Instructions) provides information concerning the location, function, operation, removal, installation, testing, adjusting, and troubleshooting of components. Maintenance methods recommended are concerned with procedures such as those which can be performed by an operating squadron.

These manuals provide the technician with an invaluable aid in locating equipment components and interconnecting cables in the aircraft, and for inspection purposes as well as troubleshooting

Before attempting any new task on an aircraft, the Maintenance Instructions Manual for that particular aircraft should be consulted. By proper use of this manual, possible damage may be prevented and much time may be saved. Recommended maintenance methods are concerned with procedures which can be accomplished by operating units, and include a Quality Assurance Summary, which indicates the minimum quality control inspection requirements for each maintenance task.

In the past, these manuals were issued as a single complete unit. They were arranged so that the pertinent sections could be removed and kept available in the shop. At present, the separate sections of these manuals are being issued as separate publications under individual identifying numbers. This facilitates procurement, storage, filing, and use of specific parts of the manual by maintenance personnel.

Avionics maintenance personnel are concerned most often with the sections covering electrical and electronic systems, radio and radar, and wiring data.

NUMBER BREAKDOWN.–Part IV of the standard designator for an aircraft Maintenance Instructions Manual indicates the subject content of the manual. This designator may consist of a single number, a number and decimal, or even a number with double decimals, as required to break down the information sufficiently. Due to the differences in operational usage of various models of aircraft, this system cannot be standardized completely. However, the following partial listing is typical for many of the new aircraft:

-2–Airframe Maintenance Instructions Manual
  -0–Maintenance Planning Data (For some models of aircraft, this data is contained in a -100 publication rather than in -2-0.)
  -1.1–General Information and Servicing
  -1.2–Corrosion Control and Decontamination
  -2–Airframe Systems
  -3–Powerplant and Related Systems
  -4–Instrument Systems
  -5–Electrical Systems
  -5.1–Electrical Power Supply System
  -5.2–Lighting System
  -6–Electronic Systems
  -7–Armanent and Related Systems
  -8–Airborne Missile Control Systems
  -9–Systems Integration
  -10–Wiring Diagrams
  -10.1–Wiring Data Diagrams
  -10.2–Wiring Data Repair

Each category may be broken down into single or double decimal subdivisions as the occasion requires.

MANUAL BREAKDOWN.–The typical volume of the MIM contains six sections as follows:

Section I–Introduction. Provides a general description of the manual, including the scope of coverage, format, and arrangement of the included information. It contains listings of applicable publications and technical directives required by operating activities pertaining to the specific model aircraft or equipment covered in the manual.

Section II–Description and Operation. Includes a physical description of the aircraft or equipment covered by the manual. It includes a detailed listing of components, with separate tables for equipment components, tube and transistor complements, and fuses and circuit breakers. For equipments, this section also incorporates detailed information regarding input and output characteristics and requirements and operating instructions. Also included is a brief discussion on the theory of operation, definition of terms, explanation of terms and symbols, simplified and partial functional diagrams, and built-in test features.

Section III–Organization Maintenance (Line and Hangar). Presents information on testing and operational checks on the various systems or components covered in the manual. It includes such information as a tools and equipment list, manpower requirements, and test procedures (with pertinent notes, warnings, and cautions). In addition, this section includes system troubleshooting charts for installed equipment, and instructions for removal and installation of the equipment.

Sections IV and V–Intermediate Maintenance (Component Repair) (Section V is not always included.) Some manuals combine all functions of maintenance into a single publication; others have various breakdowns. When this level of maintenance is included, the detailed contents parallel those of Section IV, except that the procedures for individual components (rather than the complete unit), are discussed.

Section VI–Diagrams. Contains the complete set of wiring and schematic diagrams for those units covered in the manual.

Illustrated Parts Breakdown (IPB)

The Illustrated Parts Breakdown normally consists of several individual manuals: one for each major functional element of the aircraft, and a final volume which is an index. It is identified by the -4 following the aircraft designation in the standardized publication identification system. It is useful in the procurement, requisitioning, storing, issuing, and identification of new or reclaimed parts.

It can also be used to determine the exact part or item required for replacement in a repair situation. It can also be used as a guide in reassembly of units which have been disassembled for testing, cleaning, or repair.

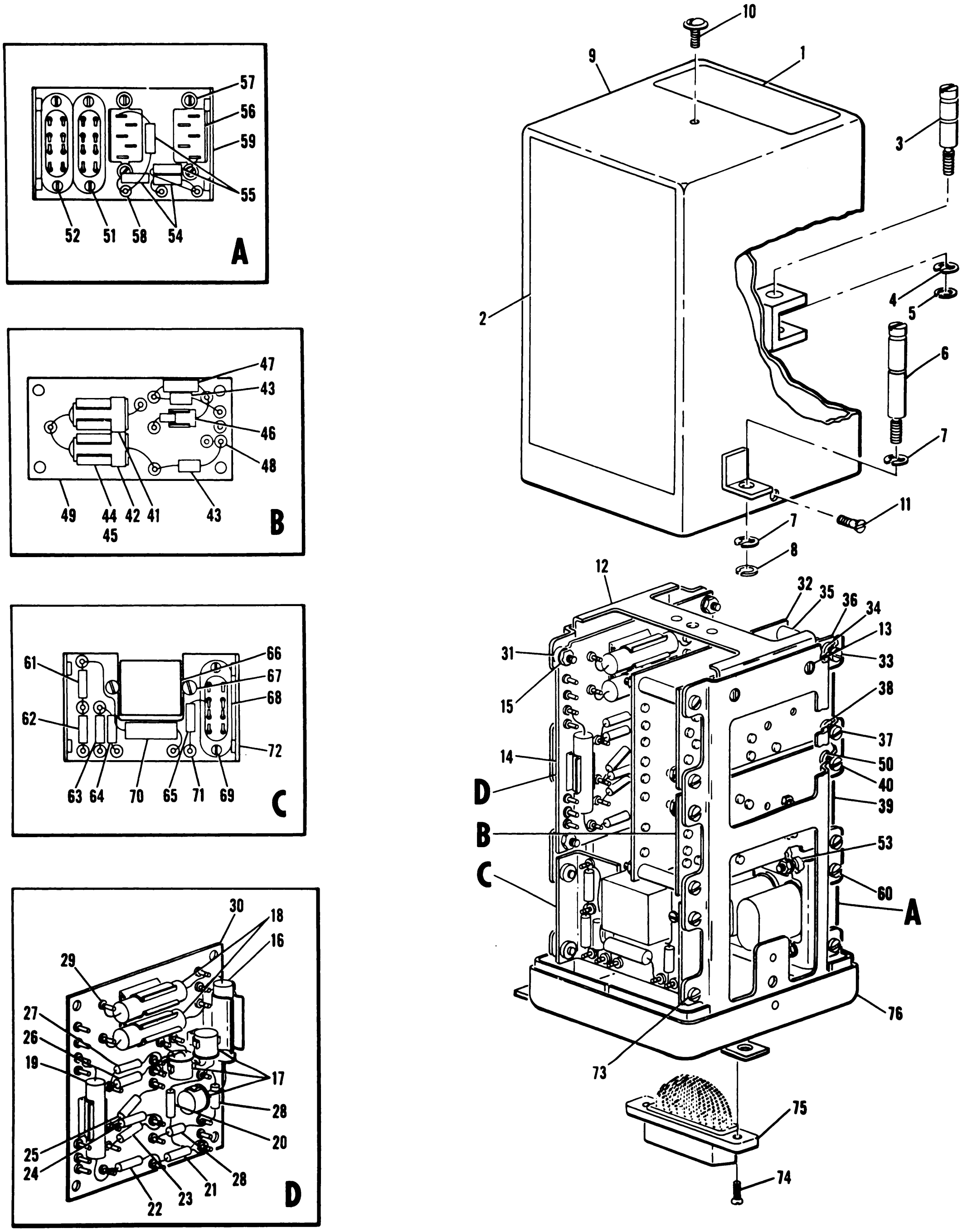
The separation of the IPB into its separate manuals does not necessarily follow the same order as the MIM breakdown; however, the type information available is consistent for nearly all IPB's.

MANUAL BREAKDOWN.–With the exception of the Index volume, each volume of the IPB follows generally the same format. It is divided into two sections–Introduction and Group Assembly Parts List.

Section I–Introduction. Contains specific detailed instructions for use of the particular IPB and the set to which it belongs.

Section II–Group Assembly Parts List. Provides reference and identification data for the various assemblies and subassemblies within the scope of the manual. For each assembly and subassembly, the data consists of a diagram and table. (See figs. 4-1 and 4-2.) The diagram indicates the location and general appearance of the item and provides clues for assembling.

Inserts A, B, C, and D illustrate items which are furnished as subassemblies of the major item. In the "description" column of the table, note the progressive indentations. The first entry is the complete assembly, and is begun flush at the left. Index numbers 1 through 15 refer to individual items of material which are parts of the assembly, and are indented one space. Index numbers 16 through 30 are bits and pieces of subassembly D and are indented two spaces. Further disassembly would be indicated by additional breakdown of one of



AT.16

Figure 4-1.—IPB, sample figure.

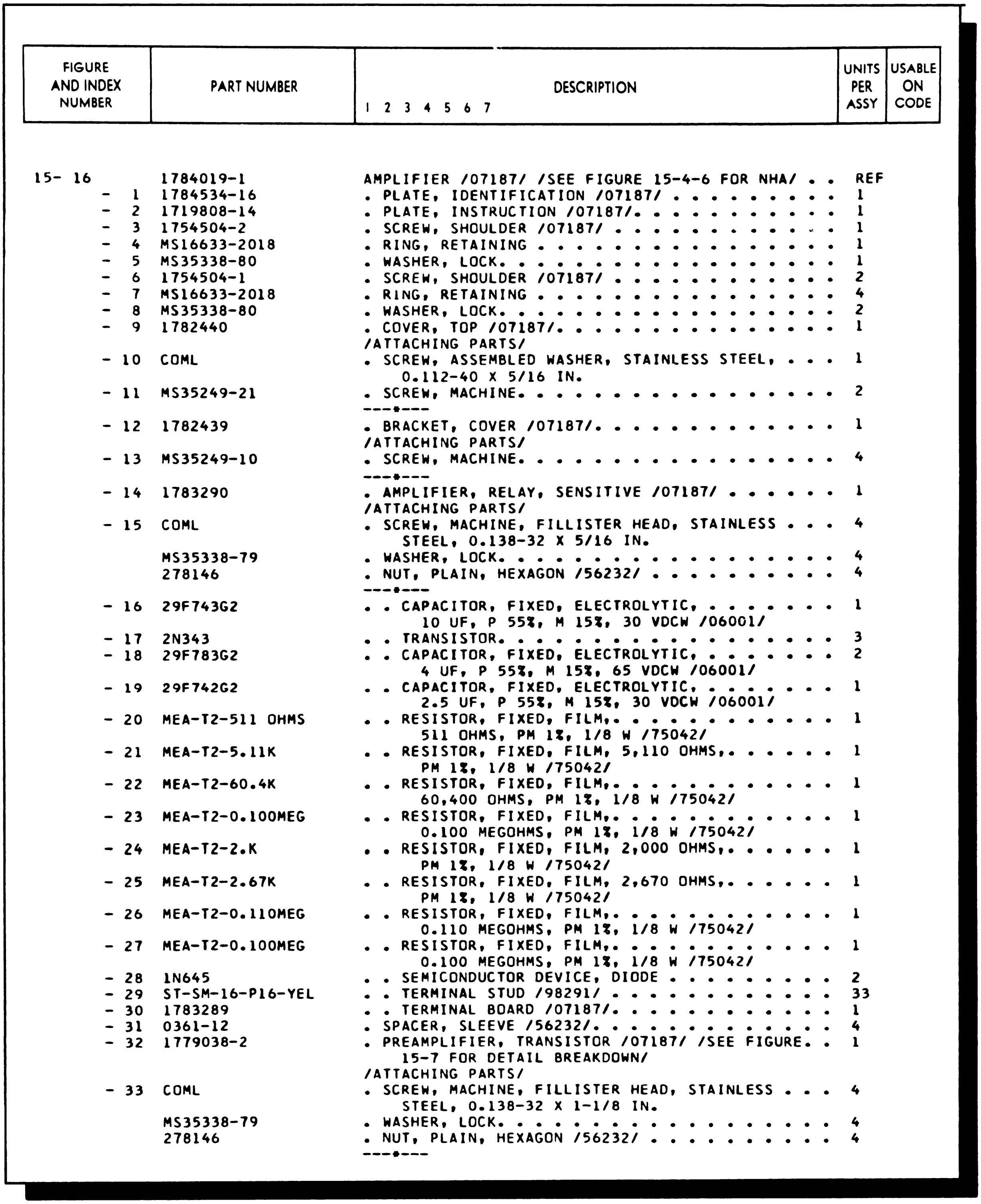


FIGURE AND INDEX NUMBER	PART NUMBER	DESCRIPTION 1 2 3 4 5 6 7	UNITS PER ASSY	USABLE ON CODE
15- 16	1784019-1	AMPLIFIER /07187/ /SEE FIGURE 15-4-6 FOR NHA/	REF	
- 1	1784534-16	. PLATE, IDENTIFICATION /07187/	1	
- 2	1719808-14	. PLATE, INSTRUCTION /07187/	1	
- 3	1754504-2	. SCREW, SHOULDER /07187/	1	
- 4	MS16633-2018	. RING, RETAINING	1	
- 5	MS35338-80	. WASHER, LOCK	1	
- 6	1754504-1	. SCREW, SHOULDER /07187/	2	
- 7	MS16633-2018	. RING, RETAINING	4	
- 8	MS35338-80	. WASHER, LOCK	2	
- 9	1782440	. COVER, TOP /07187/	1	
		/ATTACHING PARTS/		
- 10	COML	. SCREW, ASSEMBLED WASHER, STAINLESS STEEL, 0.112-40 X 5/16 IN.	1	
- 11	MS35249-21	. SCREW, MACHINE	2	
		---*---		
- 12	1782439	. BRACKET, COVER /07187/	1	
		/ATTACHING PARTS/		
- 13	MS35249-10	. SCREW, MACHINE	4	
		---*---		
- 14	1783290	. AMPLIFIER, RELAY, SENSITIVE /07187/	1	
		/ATTACHING PARTS/		
- 15	COML	. SCREW, MACHINE, FILLISTER HEAD, STAINLESS STEEL, 0.138-32 X 5/16 IN.	4	
	MS35338-79	. WASHER, LOCK	4	
	278146	. NUT, PLAIN, HEXAGON /56232/	4	
		---*---		
- 16	29F743G2	. . CAPACITOR, FIXED, ELECTROLYTIC, 10 UF, P 55%, M 15%, 30 VDCW /06001/	1	
- 17	2N343	. . TRANSISTOR	3	
- 18	29F783G2	. . CAPACITOR, FIXED, ELECTROLYTIC, 4 UF, P 55%, M 15%, 65 VDCW /06001/	2	
- 19	29F742G2	. . CAPACITOR, FIXED, ELECTROLYTIC, 2.5 UF, P 55%, M 15%, 30 VDCW /06001/	1	
- 20	MEA-T2-511 OHMS	. . RESISTOR, FIXED, FILM, 511 OHMS, PM 1%, 1/8 W /75042/	1	
- 21	MEA-T2-5.11K	. . RESISTOR, FIXED, FILM, 5,110 OHMS, PM 1%, 1/8 W /75042/	1	
- 22	MEA-T2-60.4K	. . RESISTOR, FIXED, FILM, 60,400 OHMS, PM 1%, 1/8 W /75042/	1	
- 23	MEA-T2-0.100MEG	. . RESISTOR, FIXED, FILM, 0.100 MEGOHMS, PM 1%, 1/8 W /75042/	1	
- 24	MEA-T2-2.K	. . RESISTOR, FIXED, FILM, 2,000 OHMS, PM 1%, 1/8 W /75042/	1	
- 25	MEA-T2-2.67K	. . RESISTOR, FIXED, FILM, 2,670 OHMS, PM 1%, 1/8 W /75042/	1	
- 26	MEA-T2-0.110MEG	. . RESISTOR, FIXED, FILM, 0.110 MEGOHMS, PM 1%, 1/8 W /75042/	1	
- 27	MEA-T2-0.100MEG	. . RESISTOR, FIXED, FILM, 0.100 MEGOHMS, PM 1%, 1/8 W /75042/	1	
- 28	1N645	. . SEMICONDUCTOR DEVICE, DIODE	2	
- 29	ST-SM-16-P16-YEL	. . TERMINAL STUD /98291/	33	
- 30	1783289	. . TERMINAL BOARD /07187/	1	
- 31	0361-12	. SPACER, SLEEVE /56232/	4	
- 32	1779038-2	. PREAMPLIFIER, TRANSISTOR /07187/ /SEE FIGURE 15-7 FOR DETAIL BREAKDOWN/	1	
		/ATTACHING PARTS/		
- 33	COML	. SCREW, MACHINE, FILLISTER HEAD, STAINLESS STEEL, 0.138-32 X 1-1/8 IN.	4	
	MS35338-79	. WASHER, LOCK	4	
	278146	. NUT, PLAIN, HEXAGON /56232/	4	
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AT.17

Figure 4-2.—IPB, corresponding table.

the subassemblies, and the parts descriptions would be progressively indented in the table.

Note also the system used to identify attaching parts. Index number 9 is a cover, and the attaching parts are indexed as 10 and 11. This shows that these two items are used separately to attach 9 to the assembly. Sometimes a screw, washer, and nut (set) will be listed as a single item having a single index number. In these cases, the individual parts are still identified and described in the table. An example of this is index number 15. In each case, the words "attaching parts" preceded and followed by slant marks are inserted in the table immediately following the item they are used to attach.

The table furnishes the details regarding the bits and pieces which make up the unit. It is divided into five columns.

Column 1 gives the figure and index number. This number is a three-part sequence with hyphens separating the parts. The first part references the volume or major subdivision of the IPB. The second part indicates the number of the figure referenced. The third part indicates the callout number of the specific piece to which the other information pertains. The first entry always indicates the complete subassembly, and does not normally include the third part of the sequence.

Column 2 gives the part number for the specific item. This part number is used in conjunction with the Index volume of the IPB for stock number identification.

Column 3–Description. Provides the item name, manufacturer's code number (identifiable in the vendor's listing included in Section I), specification drawings, additional breakdown reference figures, and other pertinent data.

Column 4–Units Per Assembly. Specifies the total number of a given item in a single assembly.

Column 5–Usable on Code. When a specific item is used on certain aircraft of a given model, and a different item is used on other aircraft of the same model, this column is used. When all models use the same item, this column is left blank. The coding is explained in the Introduction, Section I.

The first figure of each volume is normally of the aircraft, showing the location of the major items of the aircraft. The callout numbers are referenced in the accompanying table, and are crossindexed with the applicable IPB figure number; this table gives no details except the title of the item or assembly. This figure and table are actually included in the Introduction, Section I.

INDEX BREAKDOWN.–The Index volume of the IPB comprises three sections–Introduction, Numerical Index, and Reference Designation INDEX.

Section I–Introduction. Contains details on the contents and arrangement of the volume.

Section II–Numerical Index. Consists of a numerical index containing all items listed in the Group Assembly Parts Lists of the preceding volumes. It is divided into two parts: The first part lists all the contractor part numbers, and the second part lists all the standard and vendor part numbers. Each part of the section is divided into five columns: Part Number, Federal Stock Number, Volume Figure and Index Number, Source Code, and Accountability/Recovery Code.

Section III–Reference Designation Index. Provides a cross reference between the Reference Designation Number assigned to each item of electrical, electronics, or mechanical equipment and the part number for each such item. Reference designation numbers for each of the items of equipment are determined from the applicable section of the MIM.

USING THE IPB.–In order to derive maximum benefit from maintenance functions, certain records and reports must be compiled. The requirements for these vary somewhat in different type squadrons and in different areas. The reports and records required in each activity are determined by the maintenance supervisor as one of his administrative duties. One type report that is universally required is the Unsatisfactory Material/Condition Report (discussed in chapter 2 of this manual). This and other reports and records require details concerning parts that have failed or that have been replaced for any reason. These details are available from the IPB. The procedures for locating the information depends on what is known about the part and what data is required, as shown in the following discussion:

1. When the part number is not known, determine the function and application of the part. Turn to the Table of Contents of the IPB volume

containing the affected equipment or system and select the title that seems most appropriate. Note the illustration page number. Turn to the page indicated and locate the desired part on the illustration. From the illustration, obtain the index (callout) number assigned to the part. Refer to the accompanying description for specific information regarding the part. (If the Federal Stock Number is desired, next refer to the Index volume of the IPB. Locate the part number and note the FSN.)

2. When only the part number is known, refer to the Numerical Index. Locate the part number and note the figure and index number assigned to the part. Turn to the figure indicated, and locate the referenced index number. If a pictorial representation of the part or its location is desired, refer to the same index number on the accompanying illustration. If the FSN is desired, it may be determined directly from the Index volume by locating the part number.

3. When only the reference designation is known, refer to the Reference Designation Index. Locate the reference designation and note the figure and index number and the part number assigned. Turn to the figure indicated and locate the index number. If a pictorial representation of the part, or its location is desired, refer to the index number shown on the accompanying illustration.

Periodic Maintenance Requirements Manual (PMRM)

Periodic maintenance requirements for a particular model aircraft are contained in the -6 series of publications for that model aircraft. The series includes (in addition to the Periodic Maintenance Requirements Manual) the cards and charts used to plan and control the progress of work in scheduled maintenance actions. They provide step by step procedures for performing the minimum inspections required for each type of scheduled maintenance action.

EQUIPMENT MANUALS

Most items of electronics equipment or test equipment commonly used in naval aviation are covered by a manual or a series of manuals. These manuals are usually prepared by the contractor and distributed by the Naval Air Systems Command. Standardization has not progressed to the same extent as it has in the aircraft manuals; however, some generalizations hold true for most manuals of this group.

08 - Series

Manuals of this category usually apply to older equipments which are still in use. (One very important exception is the NAESU Digest, NavAir 08-1-503, discussed later in this chapter.) The 08- series is at present undergoing a complete reorganization and is being combined with the 16- series for electronics equipment. In the issue of the NavSup Publication 2002 used in preparing this course, the 08- entry refers the user to the 16- entry. In the 16- listing, the 08- manuals are listed preceding the 16- manuals.

16- Series

Manuals of this series are identified by a numbering system similar to that used with the aircraft manuals, consisting of a three-part designation following a prefix. The prefix and the Part I serve the same purpose and follow the same rules as outlined in the preceding section. Parts II and III are not completely standardized except for subsections 30 and 35. The subdivisions of the 16- series are listed in table 4-2.

GENERAL.–The 16-1 Series manuals include several publications of many types, the contents of which do not permit inclusion in any other subseries. They include manuals pertaining to general maintenance practices, training manuals, design guidance data, etc. Some of these manuals have been individually referenced in this chapter; some others are referenced in the current indexes of publications.

RADIO AND RADAR.–Manuals of the 5Q and 5S subseries pertain to older equipments and the manuals do not conform to present standardization format. They include miscellaneous operation and maintenance data for radio and radar equipments.

JOINT NOMENCLATURE RADIO EQUIPMENT.—Manuals of this subseries normally appear in the standard format. Part II of the identifying designator specifies the equipment to

Table 4-2. — 16- Series breakdown.

Subseries	Classification
1	General
5Q	Radio
5S	Radar
30	Joint Nomenclature Radio Equipment
35	Joint Nomenclature Radio Components
40	Signal Corps Nomenclature Equipment
45	Commercial British and Navy Radio Equipment
50	Automatic & Semiautomatic Electronic Checkout Equipment
55	Radio, Radar, Electronic, and Spare Parts Lists

which the manual applies; Part III specifies the type manual. Although Part III is not completely standardized, the number refers to the following type manuals:

Operation Instructions
Service Instructions
Overhaul Instructions
Illustrated Parts Breakdown

Many smaller and less complicated equipments combine two or more of these manuals into one volume, but each of the above manuals will be discussed separately in a later section of this chapter.

OTHER SUBSERIES.–Manuals of the 35 subseries are basically the same as those of the 30 subseries, except that they deal with components rather than complete equipments. Manuals of the 40, 45, 50, and 55 subseries cannot be readily identified as to equipment applicability.

Equipment Nomenclature System.

The Joint Communication–Electronic Nomenclature System ("AN" System), formerly known as the Joint Army-Navy Nomenclature System, is designed so that its indicators will tell at a glance many things pertinent to the item. For example, it tells whether the item is a set or a component, and such other information as where it is used, the kind of equipment, and its purpose.

An indicator for a complete set begins with the letters AN. This is followed by a slant bar and a three-letter group. The three letters of the second group give the general nature of the installation, the type of equipment, and the purpose of the equipment, respectively. Following the three-letter group is a number which indicates the specific model of the equipment. An example of the basic designation is AN/ARC-38. As can be seen in table 4-3, the letters following the slant bar mean airborne radio communications.

When the system just described is applied to a unit of the complete set, the designation is formed by replacing the letters AN with a letter-number group which indicates the type and model of the unit in question. For example, a control unit used with the AN/ARC-38 is designated C-1398/ARC-38. The letter C is an indicator letter which in this case means control. The number following C indicates the specific model of control box. Table 4-4 presents commonly used unit indicator letters that are used in the letter-number group.

Operation Instruction Manual

Operation Instruction Manuals cover the operation of specific equipments and the necessary checks and adjustments required for optimum performance. These instructions are written from the equipment operator's viewpoint and do not include all data vital to the maintenance technician.

Service Instruction Manual

The Service Instruction Manual contains information on maintenance and usage of specific equipment. It provides instructions for alining, maintaining, troubleshooting, and repairing the equipment, as well as concise tabular data on fuses, power drain, number of units, etc. Because of the quantity and complexity of the material involved, the manual is divided into several sections.

Section I, Description and Leading Particulars, gives a description of the equipment and the general principles of its operation. Included in the section is information on the interchangeability of components and any special electrical

Table 4-3–Set indicator letters.

First letter (Designed installation classes)	Second letter (Type of equipment)	Third letter (Purpose)
A - Piloted aircraft B - Underwater mobile, submarine C - Air transportable (inactivated, do not use) D - Pilotless carrier F - Fixed ground G - General ground use K - Amphibious M - Ground, mobile P - Portable S - Water surface T - Ground, transportable U - General utility V - Ground, vehicular W - Water surface and underwater combination	A - Invisible light, heat radiation B - Pigeon (do not use) C - Carrier D - Radiac E - Nupac *F - Photographic G - Telegraph or teletype I - Interphone and public address J - Electromechanical or Inertial wire covered K - Telemetering L - Countermeasures M - Meteorological N - Sound in air P - Radar Q - Sonar and underwater sound R - Radio S - Special types, magnetic, etc., or combinations of types T - Telephone (wire) V - Visual and visible light W - Armament (peculiar to armament, not otherwise covered) X - Facsimile or television Y - Data processing	A - Auxiliary assemblies (not complete operating sets used with or part of two or more sets or sets series) B - Bombing C - Communications (receiving and transmitting D - Direction finder, reconnaissance, and/or surveillance E - Ejection and/or release G - Fire-control, or searchlight directing H - Recording and/or reproducing (graphic, meteorological and sound) K - Computing L - Searchlight control (inactivated, use G) M - Maintenance and/or test assemblies (including tools) N - Navigational aids (including altimeters, beacons, compasses, racons, depth, sounding, approach, and landing) P - Reproducing (inactivated, use H) Q - Special, or combination of purposes R - Receiving, passive detecting S - Detecting and/or range and bearing, search T - Transmitting W - Automatic Flight or remote control X - Identification and recognition

*NOTE: Not for U.S. use except for assigning modification letters to previously type-designated items.

Table 4-4.—Unit indicators letters.

Comp Ind	Family Name	Example of use (Not to be construed as limiting the application of the unit indicator)
AB	Supports, antenna	Antenna mounts, mast bases, most sections, towers, etc.
AM	Amplifiers	Power, audio, interphone, radio frequency, video, electronic control, etc.
AS	Antennae, simple and complex	Arrays, parabolic type, masthead, whip or telescopic loop, dipole, reflector, etc.
*AT	Antennae, simple	For new assignments use AS.
BA	Battery, primary type	B batteries, battery packs, etc.
BB	Battery, secondary type	Storage batteries, battery packs, etc.
BZ	Signal devices, audible	Buzzers, gongs, horns, etc.
C	Controls	Control box, remote tuning control, etc.
CA	Commutator assemblies, sonar	Peculiar to sonar equipment.
CB	Capacitor bank	Used as a power supply.
CG	Cable assemblies, R-F	R-F cables, waveguides, transmission lines, etc., with terminals.
CH	Chassis, drawer, door	A framework designed to accept plug-in modules. May include circuitry and/or receptacles. Does not include the plug-in module(s). It is not a storage facility or blank chassis.
CK	Crystal kits	A kit of crystals with holders.
CM	Comparators	Compares two or more input signals.
CN	Compensators	Electrical and/or mechanical compensating regulating or attenuating apparatus.
CP	Computers	A mechanical and/or electronic mathematical calculating device.
CR	Crystals	Crystal in crystal holder.
CU	Couplers	Impedance coupling devices, directional couplers, etc.
CV	Converters (electronic)	Electronic apparatus for changing the phase, frequency, or from "one" medium to "another."
CW	Covers	Cover, bag, roll, cap, radome, nacelle, etc.
CX	Cable assemblies, non-R-F	Non-R-F cables with terminals, test leads, also composite cables of R-F and non-R-F conductors.
CY	Cases and cabinets	Rigid and semirigid structure for enclosing or carrying equipment.
D	Dispensers	Chaff, leaflet, flare, napalm, bomblet, etc.
DA	Load, dummy	R-F and non-R-F test loads.
DT	Detecting heads	Magnetic pickup device, search coil, hydrophone, etc. (see R-F).
DY	Dynamotors	Dynamotor power supply.
E	Hoists	Sonar hoist assembly, etc.
F	Filters	Bandpass, noise, telephone, wave traps, etc.
FN	Furniture	Chairs, desks, tables, etc.
FR	Frequency measuring device	Frequency meters, tuned cavity, etc.
G	Generators, power	Electrical power generators without prime movers, (see PU and PD).
GO	Goniometers	Goniometers of all types.
GP	Ground rods	Ground rods, stakes, etc.

Table 4-4.—Unit indicators letters—Continued.

Comp Ind	Family Name	Example of use (Not to be construed as limiting the application of the unit indicator)
H	Head, hand, and chest sets	Includes earphone.
HC	Crystal holder	Crystal holder less crystal
HD	Environmental apparatus	Heating, cooling, dehumidifying, pressure, vacuum devices, etc.
ID	Indicators, noncathode-ray tube	Calibrated dials and meters, indicating lights, etc. (see IP).
IL	Insulators	Strain, standoff, feed-through, etc.
IM	Intensity measuring devices	Includes SWR gear, field intensity and noise meters, slotted lines, etc.
IP	Indicators, cathode-ray tube	Azimuth, elevation, panoramic, etc.
J	Junction devices	Junction, jack and terminal boxes, etc.
KY	Keying devices	Mechanical, electrical and electronic keyers, coders, interrupters, etc.
LC	Tools, line construction	Includes special apparatus such as cable plows, etc.
LS	Loudspeakers	Separately housed loudspeakers, intercommunication station.
M	Microphones	Radio, telephone, throat, hand, etc.
MA	Magazines	Magnetic tape or wire, etc.
MD	Modulators, demodulators, discriminators	Device for varying amplitude, frequency or phase.
ME	Meters	Multimeters, volt-ohm-milliammeters, vacuum tube voltmeters, power meters, etc.
MF	Magnets or magnetic field generators	Magnetic tape or wire eraser, electromagnet, permanent magnet, etc.
MK	Miscellaneous kits	Maintenance, modification, etc., except tool and crystal (see CK, TK).
ML	Meteorological devices	Barometer, hygrometer, themometer, scales, etc.
MT	Mountings	Mountings, racks, frames, stands, etc.
MX	Miscellaneous	Equipment not otherwise classified, includes subassemblies. Do not use if better indicator is available.
MU	Memory units	Memory units.
O	Oscillators	Master frequency, blocking, multivibrators, etc. (for test oscillators, see SG).
**OA	Miscellaneous groups	Groups not otherwise classified. Do not use if a more specific indicator, such as OD, OE, OG, etc., applies.
**OB	Multiplexer and/or demultiplexer groups	Multiplexer groups, demultiplexer groups, composites thereof.
OC	Ocenographic devices	Bathythemographs, etc.
**OD	Indicator groups	All types.
**OE	Antenna groups	All types.
**OF	Adapter groups	All types.
**OG	Amplifier groups	All types.
**OH	Simulator groups	All types.
**OJ	Consoles and console groups	All types.
**OK	Control groups	All types.
**OL	Data analysis and data processing groups	All types.

Table 4-4.—Unit indicators letters—Continued.

Comp Ind	Family Name	Example of use (Not to be construed as limiting the application of the unit indicator)
**OM	Modulator and/or demodulator groups	Modulator groups, demodulator groups, composites thereof.
**ON	Interconnecting groups	All types.
**OP	Power Supply groups	All types.
**OQ	Test Set groups	All types.
**OR	Receiver groups	All types.
OS	Oscilloscope, test	Test oscilloscopes for general test purposes.
**OT	Transmitter groups	All types.
**OU	Converter groups	All types.
**OV	Generator groups	All types excluding power generating equipment.
**OW	Terminal groups	Telegraph, telephone, radio, etc.
**OX	Coder, decoder, interrogator, transponder groups	All types.
**OY	Radar Set groups	Do not use if a more specific indicator, such as OE, OR, OT, etc., applies.
**OZ	Radio Set groups	Do not use if a more specific indicator, such as OE, OR, OT, etc., applies.
PD	Prime drivers	Gasoline engines, electric motors, synchros, diesel motors, etc.
PF	Fittings, pole	Cable hanger, clamp, protectors, etc.
*PG	Pigeon articles	Container, loft, vest, etc.
*PH	Photograghic articles	Camera, projector, sensitometer, etc.
PL	Plug-in modules	Plug-in modules not otherwise classified. Do not use if more specific indicators, such as AM, R, T, apply.
PP	Power supplies	Nonrotating machine type such as vibrator pack rectifier, thermoelectric, etc.
PT	Plotting equipments	Except meteorological. Boards, maps, transparent maps, plotting table, etc.
PU	Power equipments	Rotating power equipment except dynamotors, motor-generator, etc.
R	Receivers	Receivers, all types except telephone.
RC	Reels	All types (see RL).
RD	Recorder-reproducers	Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical, etc.
RE	Relay assemblies	Electrical, electronic, etc.
RF	Radio frequency component	Composite component of R-F circuits. Do not use if better indicator is available.
RG	Cables, R-F, Bulk	R-F cable, waveguides, transmission lines, etc. without terminals.
RL	Reeling machines	Mechanisms for dispensing and rewinding antenna or field wire, recording wire or tape, etc.,
RO	Recorders	Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical, etc.
RP	Reproducers	Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical etc.
RR	Reflectors	Target, confusion, etc., except antenna reflectors (see AS).

Table 4-4.—Unit indicators letters—Continued.

Comp Ind	Family Name	Example of use (Not to be construed as limiting the application of the unit indicator)
RT	Receiver and transmitter	Radio and radar transceivers, composite transmitter and receiver, etc.
S	Shelters	House, tent, protective shelter, etc.
SA	Switching devices	Manual, impact, motor driven, pressure operated, etc.
SB	Switchboards	Telephone, fire control, power, panel, etc.
SG	Generators, signal	Test oscillators, noise generators, etc. (see O)
SM	Simulators	Flight, aircraft, target, signal, etc.
SN	Synchronizers	Equipment to coordinate two or more functions.
ST	Straps	Harness, straps, etc.
SU	Optical device	Telescopes, periscopes, projectors, and boresighting scopes.
T	Transmitters	Transmitters, all types, except telephone.
TA	Telephone apparatus	Miscellaneous telephone equipment.
TB	Towed body	Buoy, fish, paravane, target, etc.
TC	Towed cable	Articulated towing strut, faired cable, etc.
TD	Timing devices	Mechanical and electronic timing devices, range device, multiplexers, electronic gates, etc.
TF	Transformers	Transformers when used as separate items.
TG	Positioning devices	Tilt and/or train assemblies.
TH	Telegraph apparatus	Miscellaneous telegraph apparatus.
TK	Tool kits	Miscellaneous tool assemblies.
TL	Tools	All types except line construction (see LC).
TN	Tuning units	Receiver, Transmitter, antenna, tuning units, etc.
TR	Transducers	Magnetic heads, phonopickups, sonar transducers, vibration pickups, etc. (see H, LS, and M).
TS	Test items	Test and measuring equipment not otherwise included; boresighting and alignment equipment.
TT	Teletypewriter and facsimile apparatus	Miscellaneous tape, teletype, facsimile equipment, etc.
TV	Tester, tube	Electronic tube tester.
TW	Tapes and recording wires	Recording tape and wire, splicing, electrical insulating tape, etc.
U	Connectors, audio and power	Unions, plugs, sockets, adapters, etc.
UG	Connectors, R-F	Unions, plugs, sockets, choke couplings, adapters, elbows, flanges, etc.
V	Vehicles	Carts, dollies, trucks, trailers, etc.
VS	Signaling equipment, visual	Flag sets, serial panels, signal lamp equipment, etc.
WD	Cables, two-conductor	Non-R-F wire, cable and cordage in bulk (see RG).
WF	Cables, four-conductor	Non-R-F wire, cable and cordage in bulk (see RG).
WM	Cables, multiple-conductor	Non-R-F wire, cable and cordage in bulk (see RG).
WS	Cables, single-conductor	Non-R-F wire, cable and cordage in bulk (see RG).
WT	Cables, three-conductor	Non-R-F wire, cable and cordage in bulk (see RG).
ZM	Impedance measuring devices	Used for measuring Q, C, L, R, or PF, etc.

*NOTE: Inactivated for U S. use except for assigning modifcation letters to previously type-designated items

**NOTE: Collection of items part of or used with one set or set series.

or mechanical characteristics of the system or components.

Section II, Special Test Equipment and Special Tools, lists all necessary special test equipment and tools (including test racks) which are used for complete bench testing of the system or the components. Any instructions necessary for modifying the test equipment for special use or for the fabrication of a special test harness are also found in this section.

Section III, Preparation for Use and Reshipment, is divided systematically, showing the method by which the equipment should be handled from the time it is received until it is ready for use by the operator. The section contains general information on uncrating and assembling the equipment on the test bench or in the aircraft, removing it from the aircraft, and recrating it for shipment. Detailed descriptions of cable fabrication and the connections of cables to the components are also included. Applicable data on any checks and adjustments required during installation of the equipment is found in this section.

Section IV, Theory of Operation, presents a general description of the equipment first, and this is followed by the detailed explanations of the individual circuits. The general description is usually given from the viewpoint of circuit development (see the discussion later in this chapter concerning drawings and schematics), and block diagrams are used to trace the development path. The function of each unit is explained, as well as its relationship to other units in the equipment.

Section V, Organizational and Operational Maintenance, provides the instructions essential for the maintenance of the equipment by organizational maintenance personnel, and indicates the level of maintenance activities designated to perform it. Included are the preoperational and daily inspections and tests, the bench-test procedures, and the troubleshooting methods to be used by these activities. Each performance procedure in this section includes instructions essential for the proper use of test equipment in diagnosing a trouble within a specific equipment.

Section VI, Field Maintenance, includes the instructions required for servicing the equipment at the field maintenance levels. In addition to alinement and parts removal procedures, information is given for checking component functions by means of performance checks. Also contained in this section are systematic trouble isolation procedures which assist in localizing a defective part or component to a circuit or group of circuits, depending upon the nature of the equipment. Each performance procedure in this section includes instructions essential for the proper use of the test equipment in diagnosing a trouble within a specific equipment.

Section VII, Diagrams, is described later in this chapter, under the heading, "Drawings and Schematics."

Section VIII, Difference Data Sheets, may be added (when required) to provide information on improved or modified models of the original equipment.

Overhaul Instruction Manual

The Overhaul Instruction Manual provides detailed information for overhauling the electronics equipment and/or component. This includes such procedures as disassembly, cleaning, repair, recalibration, testing, and any other steps necessary for complete overhaul. The manual also includes a tabulated list of test equipment recommended for overhaul. It is issued primarily to overhaul activities because the nature of the work described is usually beyond the capacities and facilities of field maintenance activities.

Illustrated Parts Breakdown

The Illustrated Parts Breakdown for equipments is similar in format, purpose, and usage to the IPB for aircraft as previously discussed.

Combined Manuals

Frequently, especially for components and small items of electronics test equipment, two or more of the above manuals are combined into a single publication. In most of these cases, the general material content may be determined from the title, but the arrangement of sections within the manual will vary with the individual publication.

REVISIONS

In an effort to provide maintenance activities with the latest and most accurate information possible, the Naval Air Systems Command has instituted a program of continuous review and frequent revision of technical publications and manuals. These revisions are classed as formal or informal.

FORMAL revisions are printed, and are distributed as a new manual or as a partial replacement on a page-by-page basis. Formal revisions are reflected in the cumulative supplement to the BuSandA publications index. INFORMAL revisions include changes authorized by other means such as messages, notices, letters, or periodicals. They are normally "pen-and-ink" type changes.

Incorporation of Revised Material

When making a pen-and-ink change to any official publication or directive, be sure to record the source of the corrected material or the authority for the change. In this manner, subsequent users of the document will know that the change is official and also where to look for additional details. Eliminating the confusion which results from too much information, some of which may be incorrect, will make the document much more valuable as a tool for maintenance.

When making a substitute page type revision to a manual, be sure to double check that all instructions forwarded with the change copy are complied with. These instructions normally include the removal of certain pages, and substitution of other pages in their place. Be sure that all canceled pages are removed and disposed of in the proper manner, and that all pages not canceled are retained in their proper sequence.

When making a revision of any type to any official document, record the data concerning the number of the change, authority, date of the incorporation of the revision, and the name or initials of the person making the incorporation. In most technical manuals, a special page is included for this purpose.

Reporting of Errors in Manuals

As a part of the program to improve the quality and accuracy of its technical manuals, the Naval Air Systems Command has initiated a program for encouraging users to report errors and discrepancies. At the time of writing, the program applies only to certain specified types of manuals, but it is planned to expand the program to include all technical manuals. The basic reporting document is the Unsatisfactory Material/Condition Report (UR), as described in chapter 2 of this manual.

SPECIFICATIONS

A specification is a minutely detailed description or designation of the characteristics, particulars, values, or tolerances which must be met by a product or process.

The technician is concerned with specifications every time he performs an inspection, calibration, adjustment, operation, or repair on any unit of electronic equipment. In order for the equipment to fulfill its purpose, it must operate in a specified manner—it must meet definite requirements of sensitivity, power output, timing, phase, frequency, signal characteristics, etc. Specifications for a particular unit are found in the operation and inspection manuals and procedures for the applicable aircraft or equipment.

Failure of an item of electronics equipment to meet its specifications will prevent the aircraft from performing at its maximum capability. This condition calls for the removal, adjustment, repair, or calibration of the defective unit. To insure that all equipments are operating within the tolerances allowed in the specifications, operational inspections must be performed at frequent intervals, and in a precise and thorough manner.

Federal Specifications

Federal specifications are prepared under the direction of and promulgated by the Administrator of General Services, and apply to items in general usage by governmental agencies.

Military Specifications

Military specifications cover materials, products, or services used predominantly by military activities, but which may be used by other federal agencies. These specifications are issued and promulgated by the Office of Standardization, Defense Supply Agencies.

Standards

A standard is a reference or a sample set up or established by competent authority to be used as a guide for comparison or evaluation.

The technician is constantly involved with standards. Every time he measures voltages in a circuit, he is comparing the potentials in that particular circuit with the standard volt. Every time he reads a schematic or block diagram, he recognizes the standard symbols used in the drawing. Every time he reads an explanation of the theory of operation for a circuit, he recognizes and understands the meaning of standard terms. When he replaces a defective resistor or capacitor, he installs a standard item.

Standards make possible the rapid, clear, and concise communication of facts, ideas, and information; without standards, modern technology would be impossible.

FEDERAL STANDARDS.—Federal standards are documents that establish engineering and technical limitations for items, materials, processes, methods, designs, and engineering practices. These documents are for general use by governmental agencies.

MILITARY STANDARDS.—Military standards are documents that establish engineering and technical limitations and applications for items, materials, processes, methods, designs, and engineering practices. These documents are intended primarily for use by agencies of the Department of Defense.

INSTRUCTIONS AND NOTICES

The Navy Directives System is used throughout the Navy for the issuance of directive type releases. Some of these prescribe policy, organization and methods, or procedures; others contain general information. The directives system provides a uniform plan for issuing and maintaining directives; conformance is required of all bureaus, offices, activities, and commands of the Navy. Two types of releases are authorized under the plan—Instructions and Notices.

Information pertaining to action of a continuing nature is contained in Instructions. An Instruction has permanent reference value and remains in effect until the originator supersedes or cancels it. Notices contain information pertaining to action of a onetime nature. A Notice does not have permanent reference value and contains provisions for its own cancellation.

For purposes of identification and accurate filing, all directives can be recognized by the originator's authorized abbreviation; the type of release (whether an Instruction or Notice); a subject classification number; and, in the case of Instructions only, a consecutive number. (Because of their temporary nature, the consecutive number is not assigned to Notices.) This information is assigned by the originator and is placed on each page of the release.

The manner of numbering and identifying directives can be better understood by considering a typical identifier:

SECNAV	INST	5215.1A
(a)	(b)	(c) (d)

(a) The authorized abbreviation of the originator of the directive.

(b) The type of release (in this case an Instruction).

(c) The subject number of the directive (obtained from the Table of Subject Classification Numbers).

(d) The consecutive number (found only on Instructions). An originator would assign consecutive numbers to those consecutive instructions with the same subject classification number. In the example above, the subject classification number 5215 concerns "Issuance Systems." If the originator, SecNav, issued additional Instructions dealing with issuance systems, they would be assigned the numbers 5215.2, 5215.3, 5215.4, etc. The letter A indicates that this is the first reissue of the same basic directive.

Subject classification numbers are listed in the Table of Subject Classification Numbers found in SecNav Instruction P5210.11. This table contains a numerical and alphabetical listing of numbers with their related subjects, and has reference value when information or instructions of a particular nature are desired. This Instruction contains all necessary information concerning the use and procedures of the Navy Directives System.

LETTER TYPE TECHNICAL DIRECTIVES (CHANGES AND BULLETINS)

BuWeps Instruction 5215.8 established a system to promote uniformity in technical directives. This system is limited to instructions of a technical nature which are not contained in technical manuals and which cannot be satisfactorily incorporated as revisions to the manuals. NavSup Publication 2002, Cognizance Symbol I, Section VIII, Part D, together with its latest cumulative supplement, provides a checkoff list for all current technical aeronautic letter publications.

A CHANGE is a technical directive containing instructions and directions to accomplish a material change, modification, repositioning, or alteration in the physical appearance of an aircraft or equipment or the installation of different parts in subassemblies, assemblies, or components in aircraft or equipment.

A BULLETIN is a technical directive containing instructions and directions to accomplish inspections, calibrations, tests and adjustments, or additional instructions on standard rework, methods, limitations, and procedures which do not fall within the change definition.

A GENERAL BULLETIN may be used in instances where the instructions and directions apply to a number of different powerplants, airframes, etc.

An INTERIM CHANGE or an INTERIM BULLETIN is a change or bulletin directive in message form which defines the action to be taken to correct a safety or operational condition which embodies risks considered to be in need of immediate correction. Interim directives may or may not contain the final solution to the problem. Interim directives are issued only when the action classification (discussed below) is Immediate or Urgent.

Action Classification

The action classification and compliance requirements for completing the directed action are of major concern and importance. In establishing time limits, the originator has considered the type and seriousness of the deficiency, operational employment and environmental conditions affecting the deficiency, prior to accomplishment of other changes, and special tools or facilities required.

IMMEDIATE ACTION.–This type directive is concerned with problems involving safety, which would probably result in fatal or serious injury to personnel, or destruction of (or extensive damage to) property, unless corrected within extremely narrow time limits. Immediate Action directives involve the immediate discontinued use of the aircraft, engine, or equipment in the operational employment under which the adverse safety condition exists. If continued use will not involve the affected component or system in either normal or emergency situations, compliance may be deferred until (but no later than) the next periodic inspection for aircraft and engines, and no later than 6 months from date of issue for equipments.

URGENT ACTION.–A directive of this type also indicates a problem in safety conditions which could result in personnel injury or property damage unless corrected. The major difference is that time limits are not quite so close as with Immediate Action directives, but are still narrow. Operating restrictions may or may not be imposed. (This classification may also be used for mission capability changes when operational and deployment commitments are considered of overriding importance.)

Interim directives classified Urgent Action require incorporation within 60 days from date of issue in those aircraft, engines, or equipments employed under conditions in which the hazard exists. If continued operation will not involve use of the affected component under either normal or emergency situations, action may be deferred up to 180 days from date of issue.

Formal directives classified Urgent Action require incorporation not later than the next Progressive Aircraft Rework (PAR) period or overhaul for aircraft and engines, and 18 months from date of issue for equipments.

ROUTINE ACTION.–These directives indicate conditions which, if uncorrected, could eventually result in personnel injury or property damage, or could have an adverse effect on operation, maintenance, or support functions. Although a hazard may exist, the situation is not considered to be critical; therefore, action may be deferred not more than one PAR or overhaul for aircraft and engines, and 18 months from date of issue for equipments.

Noncritical changes requiring the facilities of a Naval Industrial Activity could seriously interfere with operational or deployment commitments. In this event, the change may be deferred by the controlling custodian until the next succeeding PAR or overhaul.

Title

Changes and bulletins are issued under title subjects–Airframe, Powerplant, Avionics, Accessory, Support Equipment, Aviation Armament, Air Crew System, Photographic, Clothing & Survival Equipment, and Propeller.

Numbering

The number is assigned separately for each type directive and for each title subject, in numerical sequence by date of approval (not necessarily the date of issue). Interim changes and bulletings are numbered in sequence along with formal directives; formal directives issued to supersede interims retain the same sequence number.

Occasionally directives require amendment or revision. A REVISION is a completely new edition of an existing publication, and bears the words "Rev. A" or "Rev. B" as appropriate. An AMENDMENT makes a minor change or addition to the basic directive, and is indicated by "Amendment 1" following the basic title.

Some changes are intended to be installed in stages, or by different level maintenance activities. These changes are issued as "Part I" and "Part II" of the basic directive.

Format

Although there are some slight variations in detail, all letter type technical publications conform generally to a standardized format. Only a few of the topics covered in the directive warrant discussion in this course. They are as follows:

1. Publications affected. Lists the publications which should be revised as a result of incorporation of the directive.
2. Application. Identifies the specific aircraft, engines, or equipment to which the directive applies.
3. Supply Data. Presents detailed information concerning all material and supply transactions involved in support of the directed action.
4. Detailed instructions. For the maintenance technician, this is the most important part of the directive. It presents the detailed step by step procedures to be followed in accomplishing the directed action.
5. Identification. Gives instructions for marking the unit upon completion of the action, for easy identification of those units which have undergone modification.
6. Log entry. Indicates the entry, if any, to be made on the applicable logbook.

Obsolescent Types

Many directives which were issued prior to the standardization of the directives system are still effective. These include Aviation Circular Letters, Technical Orders, Technical Notes, Aircraft Changes and Bulletins, Electronic Material Changes, and Electronic Material Bulletins. Although these directives are no longer being issued, those which have not been canceled or superseded are included in the latest edition of the NavSup 2002.

Local Action

Upon receipt of a letter type technical directive, either formal or interim, the directive must be screened by the maintenance activity to determine its applicability to units or aircraft maintained by that activity. If local compliance is required, a local maintenance instruction (discussed in chapter 2) of this manual is prepared to direct compliance by shop personnel. This local instruction provides a ready reference to determine the status of action based on that directive in the activity, and provides a record of which units have been processed.

PERIODICALS

Many periodicals of interest to the technician are published and issued by naval activities and commands. A few of the most important are discussed in the following paragraphs.

NAESU Digest

Each month the Naval Aviation Engineering Service Unit (NAESU) prepares and publishes the Digest of U.S. Naval Aviation Electronics. The Digest contains information on electrical and electronics equipment relative to operation, maintenance, installation, and supply. This is an excellent source of information dealing with new equipment and new ideas for the older equipment. It gives the latest procedures (developed by NAESU and other activities) for speeding the testing, calibration, and alinement of equipment. In general, it is as the name suggests–a "digest" of all the latest information pertaining to work in electronics. It should be on the "must read" list for all hands, and always available for ready reference.

Approach

Approach, The Naval Aviation Safety Review, is published monthly by the U.S. Naval Aviation Safety Center. It is distributed to naval aeronautical organizations on the basis of one copy for each ten personnel assigned. It presents the most accurate information currently available on the subject of aviation accident prevention. It is an unofficial publication, and its contents are not to be considered as regulations, orders, or directives. It should, however, be read each month by all aviation personnel.

Naval Aviation News

Naval Aviation News is published monthly by the Chief of Naval Operations and the Naval Air Systems Command. Its purpose is to disseminate information on aircraft, aviation training and operations, and other aeronautical matters.

This publication should be read each month by all naval aviation personnel.

All Hands

ALL HANDS, Nav-Pers-0 Series, the Bureau of Naval Personnel Career Publication, is published monthly by the Bureau of Naval Personnel for the information and interest of the naval service as a whole. It is not an official publication in the sense of constituting authority for action based on information contained therein; nor is it a statement of official policy. However, it is an important publication in that it contains information vital to naval personnel.

Distribution of All Hands is automatic to each activity, and is based on one copy for each ten personnel assigned. It should be read every month by all personnel.

Naval Ordnance BULLETIN

The Naval Ordnance BULLETIN is a CONFIDENTIAL magazine issued quarterly by the Naval Ordnance Systems Command. This Bulletin contains information concerning aviation and ordnance projects of special and general interest, including new developments. The information ranges from suggestions which should help in using present equipment to furnishing a background of information on advanced developments and concepts.

DRAWINGS AND SCHEMATICS

Nearly all technical manuals make extensive use of drawings and diagrams. The technician uses these figures in nearly every phase of his work–the location and identification of units and components, troubleshooting, signal and/or circuit tracing, installation, calibration and adjustment, testing, operation, and evaluation. He uses figures in the study of operating principles of circuits and equipments.

No one particular type illustration is suitable for all applications; therefore, many different types are required. Several of the different types are discussed in the following paragraphs. Each type has its own advantages and disadvantages.

NOTE: Blueprint Reading and Sketching, NavPers 10077-C provides many details concerning the construction of illustrations and drawings. Review of that manual should be made prior to continuing the study of this chapter.

ILLUSTRATIONS

Illustrations are commonly used to present visually the idea of a text. To this end, illustrations are used in many forms. A few of these are the photograph, line drawing, shaded sketch, cutaway view, blueprint, etc. Some of the more common illustrations are discussed briefly in this chapter.

Pictorial

Pictorial illustrations normally indicate physical appearance. They may present details concerning the location, size, construction, physical relationships of size and location, or parts arrangement. They appear throughout manuals of all types, and are useful for locating and identifying systems, equipments, components, or parts. They are used in connection with installation, inspection, servicing, operation, adjustment, calibration, troubleshooting, and repair functions.

Pictorial illustrations may be accurately detailed representations, or they may be merely generalized indications, depending on their purpose. They may be photographs, halftone or shaded sketches, or line drawings.

Cutaway View

A cutaway view is an illustration used to show some detail of construction which would be extremely difficult or impossible to show by conventional pictorial views. It is often used in connection with discussions of physical construction and the operation of mechanical devices. It is frequently used in assembly diagrams and in construction details.

Location and Dimension

Location diagrams are used to show physical position relationships, and may or may not be sufficiently detailed to show physical appearance. They are primarily useful for familiarization, and are commonly used in Flight Manuals, in the General Information and Servicing section of the Maintenance Instructions Manuals (MIM's), in the Illustrated Parts Breakdown Manual, (IPB) and in the Operation and Maintenance Instructions for equipments.

Dimension diagrams denote physical size and distance. They are useful in planning the layout of bench stations, making equipment installations, or packing materials for reshipment. They are frequently used in the general information sections of technical manuals, and in those sections devoted to familiarization, installation, and shipment. They are also frequently found in change type technical directives.

Location and/or dimension diagrams may be combined with other type illustrations, thus providing additional details without increasing the number of illustrations.

Assembly Diagrams

Assembly diagrams, as the name implies, provide details of construction which are useful in assembling parts into a unit. They are also useful in explaining the operation of mechanical or electromechanical devices.

BLOCK DIAGRAMS

Block diagrams are not used to show physical shape, size, or location; they are used to present a generalized explanation of overall functional operation. They range from very simple to very complex, depending on the type equipment, the quantity and quality of details to be covered, and the purpose for which the information is included. They are found in nearly all manuals dealing with basic or detailed theory of operation, whether of relatively simple subassemblies or of very large and complex systems. The more complex the equipment, the more probable the need for block diagrams.

Many block diagrams are used in connection with electromechanical devices, as well as with electrical or mechanical systems. Proper use of this type diagram helps increase understanding of functional relationships and operation.

Symbols

Since block diagrams are used mainly to provide a general analysis of functional operation, symbols are generally used to represent individual circuits or functional components. In order to make maximum use of block diagrams, it is essential to recognize the symbols, and to understand their meanings and limitations. Appendix II of this manual contains many of the common symbols found on block diagrams. Numerous block diagrams are included in this manual.

Signal Flow

One special type of block diagram is called the signal flow diagram or signal flow chart. It is usually used in connection with overall operation of complicated systems such as fire control computers, ASW systems, aircraft control or power distribution systems, or search or navigation radar systems. It includes all features normally associated with block diagrams, and in addition it includes considerable detail regarding signal paths, signal wave-shape, timing sequence and relationships, magnitudes of potentials or signals, frequencies, etc.

WIRING DIAGRAMS

The wiring diagram presents detailed circuitry information concerning electrical and electronics systems. A master wiring diagram is a single diagram that shows all the wiring in a complete system or in an aircraft. In most cases, this diagram would prove to be too large to be usable; it is normally broken down into logical functional sections, each of which may be further subdivided into circuit diagrams. By breaking a system into individual circuit diagrams, each individual circuit may be presented in greater detail. The increased detail provides for easier circuit tracing, testing, and maintenance.

Wiring diagrams fall into two basic classes—chassis wiring and interconnecting diagrams—each with specific purposes and many variations in appearance (depending on application). Wiring diagrams are not generally used for discussions of theory of operation of specific circuits.

Figure 4-3(A) is an example of one type chassis wiring diagram commonly used. This drawing shows the physical layout of the unit, and all component parts and interconnecting tie points are shown. Each indicated part is identified by reference designation number, thus facilitating use of the IPB to determine values and other data. (The values of resistors, capacitors, or other components are normally not indicated on wiring diagrams.) The polarity of semiconductor diodes and of the polarized capacitor is shown. Since this specific diagram shows physical layout and dimensioning details for mounting holes, it could be used as an assembly drawing and also as an installation drawing.

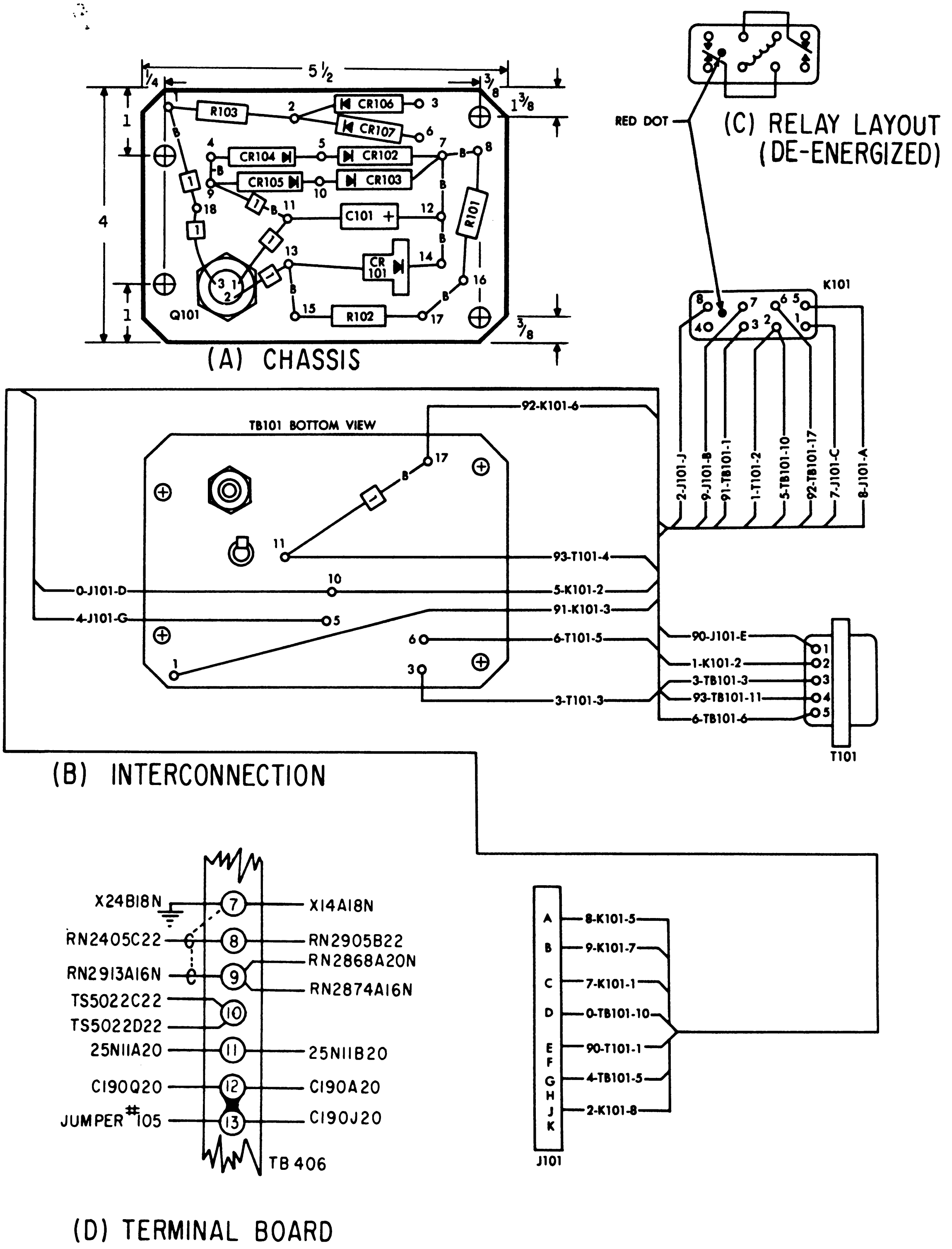
Figure 4-3 (B) shows the reverse side of the same mounting board, together with the wiring interconnections to other components. Actual positioning of circuit components is not indicated, and wire bundles are represented as single lines with the separate wires entering at an angle. (The angle indicates the direction to follow in tracing the circuit to locate the other end of the wire.)

The wire identification coding on this diagram consists of a three-part designation. The first part is a number representing the color code of the wire in accordance with Military Specification MIL-W-76A. (Many other chassis wiring diagrams designate color coding by abbreviations of the actual colors.) The second is the reference part designation number of the item to which the wire is connected. The last is the designation of the specific terminal to which connection is made.

Figure 4-3 (C), while not a wiring diagram, illustrates a method commonly used to show some functional aspect of sealed or special components.

Figure 4-3 (D) illustrates several methods used to indicate connections at terminal strips. The details of wire identification coding used are discussed below.

Wiring diagrams are normally the major content of the last volume of an MIM set, or the last section of most other maintenance manuals. This volume or section contains wiring diagrams for all electrical and electronic systems of the aircraft. The diagrams are prepared separately for each circuit and provide all data necessary to understand the construction of



(A) CHASSIS

(B) INTERCONNECTION

(C) RELAY LAYOUT (DE-ENERGIZED)

(D) TERMINAL BOARD

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Figure 4-3.—Wiring diagrams. (A) Chassis wiring; (B) interconnection wiring; (C) sealed component parts layout; (D) terminal board connections.

each circuit, to trace each circuit within the system to make continuity and resistance checks, and to perform specific troubleshooting on inoperative or malfunctioning circuits.

Aircraft Wire Identification Coding

To facilitate maintenance, all aircraft wiring is identified on the wiring diagrams exactly as marked in the aircraft. Identification of each wire is coded by a combination of letters and numbers imprinted on the wire at prescribed intervals along its entire run. Figure 4-4 and the accompanying discussion explain the code used in aircraft wiring installation. Complete details are to be found in the latest revision of MIL-W-5088.

The unit number (shown in dashed outline) is used only in those cases having more than one given unit installed in an identical manner in the same aircraft. The wiring concerned with the first such unit bears the prefix 1, and corresponding wires for the second unit have exactly the same designation except for the prefix 2, etc.

The circuit function letter identifies the basic function of the unit in accordance with table 4-5. Note that circuit function R, S, and T wiring may bear a second letter to designate the functional breakdown of the circuit.

Each wire within a given circuit function group is assigned a separate wire number. Wires that are segmented by the use of splices, plug and receptacle connectors, terminal strip tie points, etc., are given a letter segment designation. Passage through a switch, relay, circuit breaker, etc., requires assignment of a new number.

Wire size numbers are omitted in the case of coaxial cables; they are replaced by a dash and coded designator when part of a thermocouple arrangement.

A suffix is added to designate the phase (or ground) in 3-phase a-c power wiring. In the case of thermocouples the suffix denotes the metal element involved.

Cable Construction

Cable construction diagrams present details concerning the fabrication and construction of cables. These details usually include designation of the type connectors or terminals, the identification of wires for each terminal, method of connecting wire to terminal, potting requirements, length of wires, lacing or sleeving specifications, and any other specifications, or special considerations involved.

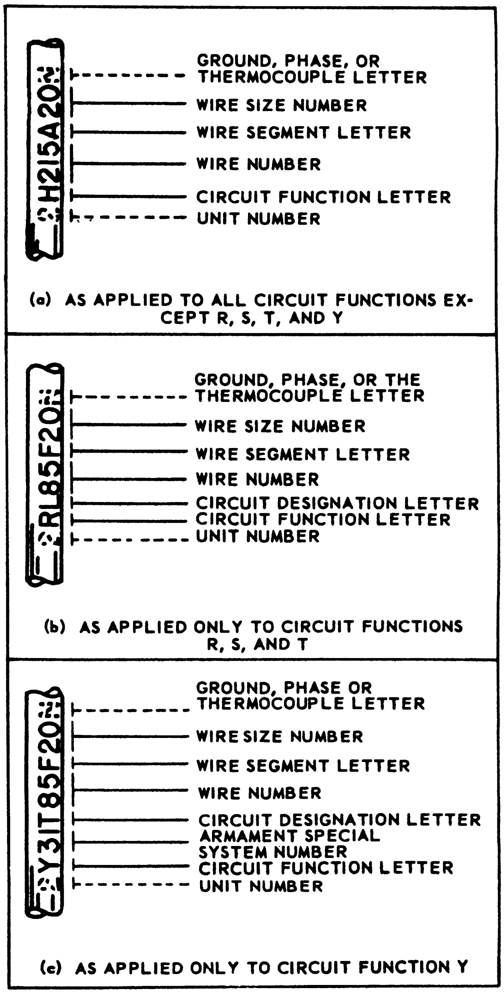
2H215A20N
GROUND, PHASE, OR THERMOCOUPLE LETTER
WIRE SIZE NUMBER
WIRE SEGMENT LETTER
WIRE NUMBER
CIRCUIT FUNCTION LETTER
UNIT NUMBER
(a) AS APPLIED TO ALL CIRCUIT FUNCTIONS EXCEPT R, S, T, AND Y
2RL85F20N
GROUND, PHASE, OR THE THERMOCOUPLE LETTER
WIRE SIZE NUMBER
WIRE SEGMENT LETTER
WIRE NUMBER
CIRCUIT DESIGNATION LETTER
CIRCUIT FUNCTION LETTER
UNIT NUMBER
(b) AS APPLIED ONLY TO CIRCUIT FUNCTIONS R, S, AND T
2Y31T85F20N
GROUND, PHASE OR THERMOCOUPLE LETTER
WIRE SIZE NUMBER
WIRE SEGMENT LETTER
WIRE NUMBER
CIRCUIT DESIGNATION LETTER
ARMAMENT SPECIAL SYSTEM NUMBER
CIRCUIT FUNCTION LETTER
UNIT NUMBER
(c) AS APPLIED ONLY TO CIRCUIT FUNCTION Y

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Figure 4-4.–Example of wire Identification coding.

Cable Routing

Diagrams of major systems generally include an isometric shadow outline of the aircraft showing the approximate location of equipment components, and the physical routing of inter-

Table 4-5. —Wiring circuit function code.

Circuit function letter	Circuits
A	Armament
B	Photographic
C	Control surface
D	Instrument
E	Engine instrument
F	Flight instrument
G	Landing gear
H	Heating, ventilating, and de-icing
J	Ignition
K	Engine control
L	Lighting
M	Miscellaneous
P	D-c power
	Wiring in the d-c power or power control system will be identified by the circuit function letter P.
Q	Fuel and oil
R	Radio (navigation and communication)
	RN-Navigation
	RP-Intercommunications
	RZ-Interphone, headphone
S	Radar
	SA-Altimeter
	SN-Navigation
	SQ-Track
	SR-Recorder
	SS-Search
T	Special electronic
	TE - Countermeasures
	TN-Navigation
	TR-Receivers
	TX-Television transmitters
	TZ-Computer
V	D-c power and d-c control wires for a-c systems will be identified by the circuit function letter V.
W	Warning and emergency
X	A-c power
	Wiring in the a-c power system will be identified by the circuit function letter X.
Y	Armament special systems

connecting cables. A cable, regardless of the number of conductors, is represented on an isometric wiring diagram as a single line; no attempt is made to show individual connections at equipment units or in connection boxes. An isometric type drawing thus shows at a glance a picture of the layout of the entire system.

SCHEMATICS

The major purpose of the schematic diagram is to establish the electrical operation of a particular system. It is not drawn to scale, and it shows none of the actual construction details of the system (such as a physical location within the aircraft, physical layout of components, wire routing, or any other physical detail) not essential to understanding circuit operation.

Schematic drawings differ from block diagrams (discussed earlier) by presenting more detail concerning each circuit. Whereas the block diagram deals with functional units of the system, the schematic diagram indicates each individual part which contributes to the functional operation of the circuit.

NOTE: The National Bureau of Standards is now using in all its publications the term hertz, abbreviated Hz, as the term applied to a unit of frequency, one hertz being one cycle per second. Table 4-6 will give you a quick rundown of a few applications of the term to show you how it works.

Simplified Schematics

In large or complex equipments, a complete schematic drawing may be too large for practical use. For this reason, most technical manuals present partial or simplified schematics for individual circuits or units.

Simplified schematics normally omit parts and connections which are not essential to understanding circuit operation. In studying or troubleshooting equipment, the technician frequently must make his own simplified drawings. In these cases he should include only those items that contribute to the purpose of the drawing, but he should take care to include all such items. In using the schematic drawings throughout this manual (and those in technical manuals, textbooks, and other publications), many techniques for simplifying schematics will become apparent. Special attention should be paid to those techniques found useful by the individual maintenance man—they can be extremely important tools in his work.

Electromechanical Drawings

Electromechanical devices such as synchros, gyros, accelerometers, autotune systems, analog computing elements, etc., are quite common in avionics systems. For a complete understanding of these units, neither an electrical drawing nor a mechanical drawing would be adequate—and confusion could result from the use of two drawings. Therefore a com-

Table 4-6.—Hertz table.

Unit/quantity	Old term	Old abbrev.	New term	New abbrev.
Frequency	Cycles Per Second	cps	hertz	Hz
10^{-3} Cycles Per Second	Millicycles Per Second	mc	Millihertz	mHz
10^{3} Cycles Per Second	Kilocycles Per Second	kc	Kilohertz	kHz
10^{6} Cycles Per Second	Megacycles Per Second	Mc	Megahertz	MHz
10^{9} Cycles Per Second	Gigacycles Per Second	Gc	Gigahertz	GHz

bination type drawing, using some aspects of each component type, is used. These drawings are usually simplified both electrically and mechanically, and only those items essential to the operation are indicated on the drawing.

CHARTS AND TABLES

Charts and tables of many types are used throughout all types of technical publications to present factual data in a clear and concise form. As the terms are used in this discussion, a chart is used to present information in lists, pictures, tables, or diagrams; a table is one type of chart, and is used to present or list information in a very condensed form.

Tables prove valuable in instances when the same general type information is to be presented with respect to numerous items. The corresponding details for the items may be listed in columns, arranged so that reading across will present details regarding a specific item, while reading down will present a comparison of items with respect to a certain detail. One very common and useful table of this type is represented by the IPB listings discussed earlier in this chapter.

SECURITY OF CLASSIFIED MATERIAL

It is important that all personnel in the Naval Establishment be aware of (and comply with) regulations governing the use and safeguarding of classified material and information. The basic policy governing security is established and detailed in the Department of the Navy Security Manual for Classified Material, OpNav Instruction 5510.1 (Series). This manual is to be used as a guide by all naval personnel in the handling of classified material. Many of the electronics equipments installed in modern aircraft (and their applicable technical publications) bear security classification, so it is especially important that all personnel in the avionics ratings become thoroughly familiar with security procedures.

It is the personal responsibility of each individual to safeguard all classified material in his possession so as to prevent loss or compromise. It is also his responsibility to avoid unauthorized disclosure of classified information. Material of a classified nature should not be passed on to any person not having the proper security clearance and the need to know.

In contacts with other persons, do not assume that they have the proper security clearance; be SURE before revealing classified information. In conversations and in writing, avoid compromising security. Do not pass any information to unknown personnel until it is sure that the information is not classified.

Remember that notes jotted down concerning classified material may contain classified information, and must be handled accordingly.

CHAPTER 5

ELEMENTARY PHYSICS

The Navy technician is associated with some very complex machines and equipment. He is expected to understand, operate, service, and maintain these machines and equipment, and to instruct new men so that they can also perform these functions. No matter how complex a machine or item of equipment is, its action can be satisfactorily explained as an application of a few basic principles of physics. In order to understand, maintain, and repair the equipment and machinery necessary to the operation of the ships and aircraft of the fleet, an understanding of these basic principles is essential. There can be no question that the technician who possesses this understanding is better equipped to meet the demands placed upon him in his everyday tasks.

Physics is devoted to finding and defining problems, as well as to searching for their solutions. It not only teaches a person to be curious about the physical world, but also provides a means of satisfying that curiosity. The distinction between physics and other sciences cannot be well defined, because the principles of physics also pertain to the other sciences. Physics is a basic branch of science and deals with matter, motion, force, and energy. It deals with the phenomena which arise because matter moves, exerts force, and possesses energy. It is the foundation for the laws governing these phenomena, as expressed in the study of mechanics, hydraulics, magnetism, electricity, heat, light, sound, and nuclear physics. It is closely associated with chemistry and depends heavily upon mathematics for many of its theories and explanations.

BASIC CONCEPTS

In any study of physics, it soon becomes obvious that specific words and terms have specific meanings which must be mastered from the very start. Without an understanding of the exact meaning of the term, there can be no real understanding of the principles involved in the use of that term. Once the term is correctly understood, however, many principles may be discussed briefly to illustrate or to emphasize the particular aspects of interest. The first part of this chapter is devoted to definitions of some physical terms and a brief general discussion of certain particular principles of vital interest to all technical personnel.

MEASUREMENT

In all branches of science, measurement is a very important consideration. In order to evaluate results, it is often essential to know how much, how far, how many, how often, or in what direction. As scientific investigations become more complex, measurements must become more accurate, and new methods must be developed to measure new things.

Measurements may be classed in three broad categories—magnitude, direction, and time. These categories are broken down into several types, each with its own standard units. Measurements of direction and time have become fairly well standardized and have comparatively few subdivisions. Magnitude, on the other hand, is an extremely complex category with many classes and subdivisions involved.

To illustrate the complexity of the magnitude category, consider only a few common examples of measurement dealing with magnitude: weight, distance, temperature, voltage, size, loudness, brightness, etc.; then consider measurements based on combinations of magnitude: density (weight per unit volume), pressure (force per unit are), thermal expansion (increase in size per degree change in temperature), etc. In addition, measurements combine categories: The flow of liquids is measured in volume per unit of time, speed is measured in distance per unit of time, rotation is measured in revolutions per minute, frequency is expressed in cycles per second, (hertz) and so on indefinitely.

The importance of measurement and the necessity of selecting the proper measurement cannot be overemphasized. Several systems of measurement further complicate matters. For example, distance may be measured in feet or in meters; weight in pounds or in kilograms; capacity in quarts or in liters; temperature in degrees Fahrenheit, centigrade, or Kelvin; density in pounds per cubic foot or in grams per cubic centimeter; angles in degrees or in radians; etc.

In this manual, as in many other texts, specific measurements will be described when and as necessary for clarity.

MATTER AND ENERGY

MATTER may be defined basically as "anything that occupies space and has weight or mass." It exists naturally in three states–solid, liquid, or gas. All matter is composed of small particles called molecules. Matter may be changed or combined by various methods–physical, chemical, or nuclear. Matter has many properties; properties possessed by all forms of matter are called general properties, while those properties possessed only by certain classes of matter are referred to as special properties.

ENERGY may be defined basically as "the capacity for doing work." It may be classified in many ways; but for this discussion, energy will be classified as mechanical, chemical, radiant, heat, light, sound, electrical, or magnetic. Energy is constantly being exchanged from one object to another and from one form to another. Physics is primarily the study of matter and energy in their various forms and of the relationships that exist between them.

Law of Conservation

Matter may be converted from one form to another with no change in the total amount of matter. Energy may also be changed in form with no resultant change in the total quantity of energy. In addition, a third statement has been added within the past half century: "Although the total amount of matter and energy remains constant, matter can be converted into energy or energy into matter." This statement is known as the law of conservation for energy and matter. The basic mathematical equation which shows the relationship between matter and energy is as follows:

$$E = mc^2$$

where E represents the amount of energy, m represents the amount of matter (mass), and c represents the velocity of light.

From the equation it may be seen that the destruction of matter creates energy, and that the creation of matter requires expenditure of energy. From this observation it may be implied that a given quantity of matter is the equivalent of some amount of energy. In common usage it is usually stated that matter "possesses" energy.

General Properties of Matter

Matter in all forms possesses certain properties. In the basic definition it has been stated that matter occupies space and has mass. Those two ideas contain most, if not all, of the general properties of matter.

SPACE.–The amount of space occupied by, or enclosed within, the bounding surfaces of a body is called volume. In the study of physics, this concept must be somewhat modified in order to be completely accurate. As stated previously, matter may appear as a solid, as a liquid, or as a gas–each having special properties. In a later section of this chapter it will be shown that for even a specific substance the volume may vary with changes in circumstances. It will also be shown that liquids and solids tend to retain their volume when physically moved from one container to another; gases tend to assume the volume of the container.

It will be discussed at some length later that all matter is composed of atoms and molecules. In order to clarify our concept of "occupying space," we must deal with these minute particles of matter, which are in turn composed of still smaller particles separated from each other by empty space (which contains no matter). This idea is used to explain two general properties of matter–impenetrability and porosity.

Two objects cannot occupy the same space at the same time; this is known as the "impenetrability of matter." The actual space occupied by the individual subatomic particles cannot be occupied by any other matter. The impenetrability of matter may, at first glance, seem invalid when a cup of salt is poured into a cup of water–the result is considerably less than two cups of salt water. However, matter has an additional general property called "porosity" which explains this apparent loss of volume: The water simply occupies space between particles of salt. Porosity is present in all material–but to an extremely wide range of degree. Generally, gases are extremely porous, liquids only slightly so; solids vary over a wide range, from the sponge to the steel ball.

WEIGHT.–The concept of weight is also quite complicated and involves two general properties of matter–inertia and gravitational attraction. Before discussing weight, these two general properties and the concepts of motion and force must be discussed.

MOTION may be defined as the "act or process of changing place or position." The "state of motion" refers to the amount and the type of motion possessed by a body at some definite instant (or during some interval) of time. A body at rest is not changing in place or position; it is said to have zero motion, or to be motionless.

The natural tendency of any body at rest is to remain at rest; a moving body tends to continue moving in a straight line with no change in speed or direction. A body which obeys this natural tendency is said to be in uniform motion.

Every object tends to maintain a uniform state of motion. A body at rest never starts to move by itself; a body in motion will maintain its speed and direction unless it is caused to change. In order to cause a body to deviate from its condition of uniform motion, a push or a pull must be exerted on it. This requirement is due to that general property of all matter known as INERTIA.

The greater the tendency of a body to maintain uniform motion, the greater its inertia. To assign a numerical value to the inertia of a body, it is compared with some standard which is assigned the inertia value of 1. The quantitative measure of inertia is called the MASS of the body; therefore, since all matter possesses inertia, all matter must also possess mass.

Any change in the state of motion of a body is known as ACCELERATION, and the cause which produces it is called an accelerating force. Acceleration represents the rate of change in the motion of a body, and may represent either an increase or a decrease in speed and/or a change in direction of motion.

FORCE is the action or effect on a body which tends to change the state of motion of the body acted upon. A force may tend to move a body at rest; it may tend to increase or decrease the speed of a moving body; or it may tend to change the direction of motion. The application of a force to a body does not necessarily result in a change in the state of motion; it may only TEND to cause such a change.

A force is any push or pull which acts on a body. Water in a can exerts a force on the sides and bottom of the can. A tug exerts a push or a pull (force) on a barge. A man leaning against a bulkhead exerts a force on the bulkhead.

In the above examples, a physical object is exerting the force and is in direct contact with the body upon which the force is being exerted. Forces of this type are called contact forces. There are other forces which act through empty space without contact–in some cases without even seeming to have any mass associated with them. The force of gravity exerted on a body by the earth–known as the weight of the body–is an example of a force that acts on a body through empty space and without contact. Such a force is known as an action-at-a-distance force. Electric and magnetic forces are other examples of these action-at-a-distance forces. The space through which these action-at-a-distance forces are effective is called a force field.

Force is a VECTOR quantity; that is, it has both direction and magnitude. A force is completely described when its magnitude, direction, and point of application are given. In a force vector diagram, the starting point of the line represents the point of application of the force. (The topic of vectors—properties, functions, uses, and methods of calculation—is discussed in detail in Rate Training Manual, Mathematics Vol. 2, NavPers 10071-B.)

Any given body, at any given time, is subjected to many forces. In many cases, all these forces may be combined into a single RESULTANT force, which may then be used to determine the total effect on the body. Combination of all individual forces into a single resultant involves the use of trigonometry, which is also covered in NavPers 10071-B.

Each body of matter in the universe attracts every other body with a force which is proportional to the mass of the bodies and inverse to the square of the distance between them. This force is called the UNIVERSAL FORCE OF GRAVITATIONAL ATTRACTION. Since every body exerts this force on every other body, when considering the forces acting on a single body, it is an almost universal practice to resolve all gravitational forces into a single resultant. At or near the surface of the earth, this becomes a fairly simple process—due to its extremely large mass, the earth exerts such a large gravitational attraction that it is entirely practical to ignore all other such attractions and merely use the earth's gravitational attraction as the resultant.

Although gravitational attraction is exerted by each body on the other, in those cases where there is a great difference in the mass of two bodies, it is usually more convenient to consider the force as being exerted by the larger mass on the smaller mass. Thus, it is commonly stated that the earth exerts a gravitational force of attraction on a body. The gravitational attraction exerted by the earth on a body is called GRAVITY.

The gravitational force exerted by the earth on a body is called the WEIGHT of that body, and is expressed in force units. In the English system, force is expressed in pounds. If a body is attracted by a gravitational force of 160 pounds, the body is said to weigh 160 pounds. The gravitational force between two bodies decreases as the distance between them increases; therefore, a body weighs less a mile above the surface of the ocean than it weighs at sea level; it weighs more a mile below sea level.

Conversion of Mass and Weight

The relationship of mass, weight, and gravity may be expressed mathematically by the formula

$$\text{mass} = \frac{\text{weight}}{\text{acceleration due to gravity}}$$

This relationship is valid for any system of measurement, provided only that all measurements are taken in the same system.

In the English system of measurement, the mass is normally measured in slugs, weight in pounds, and acceleration (due to gravity) in feet per second per second. Therefore, the equation in English terms is

$$m = \frac{w(\text{lb})}{g(\text{ft/sec}^2)}$$

(A slug is frequently defined in terms of force and acceleration: A slug is that mass, which, when acted upon by a force of 1 pound, will be accelerated by 32 ft/sec^2.)

In problems involving the use of mass, it is usually convenient to substitute w/32 for m and the weight of the body for w in the equation. (The 32 comes from the fact that the acceleration due to gravity is 32 ft/sec^2.)

Example 1: If a body has a mass of 5 slugs, its weight (in pounds) at sea level (as measured with a spring balance) may be determined from the formula

$$m = \frac{w}{g}$$

Rearranged to solve for the necessary quantity, this formula becomes

$$w = mg$$

Substituting the numerical values,

$$w = 5 \times 32$$

$$w = 160 \text{ lb}$$

The spring-balance weight of the object is 160 lb at sea level.

Example 2: At an altitude where the acceleration due to gravity is only 31.5 ft/sec^2, what is the weight of the 5-slug mass? By using the same equation and substituting numerical values

$$w = mg$$

$$w = 5 \times 31.5$$

$$w = 157.5 \text{ lb}$$

These examples illustrate how weight varies as a result of a change in the force of gravity due to a change in altitude. The value of 32 feet per second per second usually assigned g is only an approximation used when measurements are made at or near sea level. Altitude affects the weight of an object, but its mass remains constant everywhere.

It is interesting to note that spring weighing machines are not legal for trade in most states of the U.S. A spring scale registers the force necessary to overcome the pull which gravitational force exerts on the object being weighed. This gravitational force varies with the altitude of the object on the earth. A balancing scale, usually called a BALANCE, measures mass rather than weight, although the dial is marked in pounds. On a balance, the object to be weighed is compared with a standard unit of mass. The variation due to altitude is canceled because it affects both the standard unit and the object to be weighed. Therefore, the standard mass serves as an accurate unit of measure for all locations on the surface of the earth.

Density and Specific Gravity

The DENSITY of a substance is its weight per unit volume. A cubic foot of water weighs 62.4 pounds; the density of water is 62.4 pounds per cubic foot. (In the metric system the density of water is 1 gram per cubic centimeter.)

The SPECIFIC GRAVITY (S.G.) of a substance is the ratio of the density of the substance to the density of water—

$$\text{S.G.} = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}$$

Specific gravity is not expressed in units but as a pure number. For example, if a substance has a specific gravity of 4, 1 cubic foot of the substance weighs 4 times as much as a cubic foot of water—62.4 times 4 or 249.6 pounds. In metric units, 1 cubic centimeter of a substance with a specific gravity of 4 weighs 1 times 4 or 4 grams. (Note that in the metric system of units, the specific gravity of a substance has the same numerical value as its density.)

Specific gravity and density are independent of the size of the sample under consideration, and depend only upon the substance of which the sample is made. See table 5-1 for typical values of specific gravity for various substances.

A great deal of ingenuity is often needed to measure the volume of irregularly shaped bodies. Sometimes it is practical to divide a body into a series of regularly shaped parts and then apply the rule that the total volume is equal to the sum of the volumes of all individual parts.

Table 5-1.—Typical values of specific gravity.

Substance	Specific gravity
Aluminum	2.7
Brass	8.6
Copper	8.9
Gold	19.3
Ice	0.92
Iron	7.8
Lead	11.3
Platinum	21.3
Silver	10.5
Steel	7.8
Mercury	13.6
Ethyl alcohol	0.81
Water	1.00

Figure 5-1 demonstrates another method of measuring the volume of small irregular bodies The volume of water displaced by a body submerged in water is equal to the volume of the body.

A somewhat similar consideration is possible for floating bodies. A floating body displaces its own weight of liquid. This may be proved by filling a container to the brim with liquid, then gently lowering the body to the surface of the liquid and catching the liquid that flows over the brim. Weighing the liquid displaced and the original body will prove the truth of the statement.

Pressure and Total Force

Pressure and force, while closely related topics, are not the same thing. A weight of 10 pounds resting on a table exerts a force of 10 pounds. However, the shape of the weight must be taken into consideration to determine the effect of the weight. If the weight consists of a thin sheet of steel resting on a flat surface, the effect is quite different than if the same sheet of steel were resting on a sharp corner.

Pressure is concerned with the distribution of a force with respect to the area over which that force is distributed. Pressure is defined as the force per unit of area, or $P = F/A$. A flat pan of water with a bottom area of 24 square inches and a total weight of 72 pounds exerts a total force of 72 pounds, or a pressure of 72/24 or 3 pounds per square inch, on the flat table. If the pan is balanced on a block with a surface area of 1 square inch, the pressure is 72/1 or 72 pounds per square inch. An aluminum pan with a thin bottom is suitable for use on a flat surface, but may be damaged if placed on the small block.

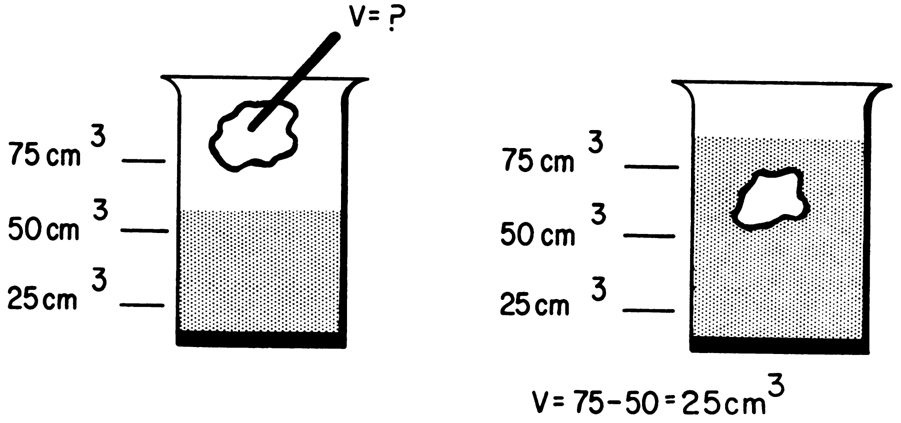
This concept explains why a sharp knife cuts more easily than a dull one. The smaller area concentrates the applied force (increases the pressure) and penetrates more easily. For hydraulic applications, the relationship between pressure and force is the basic principle of operation. In enclosed liquids under pressure, the pressure is equal at every point on the surfaces of the enclosing container, and therefore the force on a given surface is dependent on the area. In a system consisting of two cylinders connected by a tube, the force on the pistons is proportional to the area.

Kinetic Energy

Moving bodies possess energy because, by virtue of their mass in motion, they are capable of doing work. The energy of mass in motion is called KINETIC energy, and may be expressed by the equation

$$\text{Kinetic energy} = 1/2\, mv^2$$

where m represents the mass of the body, and v is the velocity of its motion. When the moving



AT.20

Figure 5-1.–Measuring the volume of an irregular object.

body is stopped, it loses its kinetic energy. The energy is not destroyed, but is merely converted into other forms of energy, such as heat and POTENTIAL energy. It is important to remember that bodies at rest also possess energy by virtue of their position.

COMPOSITION OF MATTER

Many basic facts concerning the structure and composition of matter are presented in Basic Electricity, NavPers 10086-B, and in Basic Electronics, NavPers 10087-B (in connection with the study of transistors). Study of these basic manuals indicates that all matter is composed of atoms, and that these atoms are, in turn, composed of smaller subatomic particles.

The subatomic particles of major interest in elementary physics are the electron, the proton, and the neutron. They may be considered electrical in nature, with the proton representing a positive charge, the electron representing a negative charge, and the neutron being neutral (neither positive nor negative). Although in general the composition of matter follows a consistent pattern for all atoms, the detailed arrangement of subatomic particles is different for each distinct substance. It is the combination and arrangement of the subatomic particles which imparts the distinguishing chemical and physical characteristics to a substance.

The protons and the neutrons of an atom are closely packed together in a nucleus (core), with the electrons revolving around the nucleus. Atoms are normally considered to be electrically neutral—that is, they normally contain an equal number of electrons and protons; but this condition does not actually prevail under all circumstances. Atoms which contain an equal number of electrons and protons are called balanced atoms; those with an excess or a deficiency of electrons are called "ions."

The proton and the neutron have approximately the same mass, which is approximately 1,836 times the mass of an electron. In any atom, nearly all the mass is contained in the nucleus. It may be assumed that under normal conditions any change in the composition of the atom would involve a change in the number of arrangement of the electrons (due to the smaller mass, they are more easily repositioned). This assumption is generally correct—the most notable exception being in the field of nuclear physics, or nucleonics. In chemistry and in general physics, (including electricity and electronics), it is the electron complement that is of major concern.

ELEMENT

The word element is used to denote any one of about 100 substances which comprise the basic substance of all matter. Two or more elements may combine chemically to form a compound; any combination which does not result in a chemical reaction between the different elements is called a mixture. The atom represents the smallest particle of an element. An atom of any one element differs from an atom of any other element in the number of protons in the nucleus; all atoms of a given element contain the same number of protons. Thus, it may be seen that the number of protons in the nucleus determines the type of matter.

The various elements are frequently tabulated according to the number of protons. The number of protons in the nucleus of the atom is referred to as the atomic number of the element.

Nucleus

The study of the nucleus of the atom, known as nucleonics or nuclear physics, is the subject of extensive modern investigation. Experiments on nuclei usually involve the bombardment of the nucleus of an atom, using various types of nuclear particles. By this method the composition of the nucleus is changed, usually resulting in the release of energy. The change to the nucleus may occur as an increase or a decrease in the number of protons and/or neutrons.

If the number of protons is changed, the atom has become an atom of a different element. This process, called "transmutation," is the process sought by the alchemists of the middle ages in their attempts to change various metals into gold. Scientists of that period believed transmutation could be accomplished by chemical means—hence the impetus given to the development of chemistry.

If, on the other hand, only the number of neutrons in the nucleus is changed, the atom remains an atom of the same element. Although all the atoms of any particular element have the same number of protons (atomic number), atoms of certain elements may contain various numbers of neutrons. Hydrogen (the sole exception to the rule that all atoms are composed of three kinds of subatomic particles) normally contains a single proton and a single electron—and no neutrons. However, some hydrogen atoms do contain a neutron. Such atoms (although they are atoms of hydrogen) are known as deuterium, or "heavy hydrogen." (They are called "heavy" because the addition of the neutron has approximately doubled the weight of the atom. Deuterium figured prominently in the research which led to the development of nuclear energy and the atomic bomb.) The atomic weight of an atom is an indication of the total number of protons and neutrons in the atomic nucleus.

Atoms of the same element but which have different atomic weights are called isotopes. Nearly all elements have several isotopes; some are very common, and some are very rare. A few of the isotopes occuring naturally and most of those produced by nuclear bombardment are radioactive or have unstable nuclei. These unstable isotopes undergo a spontaneous nuclear bombardment which eventually results in either a new element or a different isotope of the same element. The rate of spontaneous radioactive decay is measured by "half-life" which is the time required for one-half of a sample of radioactive material to change (by spontaneous radioactive decay) into a different substance.

Electron Shells

The physical and chemical characteristics of an element are determined by the number and distribution of electrons in the atoms of that element. The electrons are arranged in successive groups of electron shells of rotation around the nucleus; each shell can contain no more than a specific number of electrons, as described in chapter 2 of Basic Electronics, NavPers 10087-B. An INERT element (that is, an element which does not combine chemically with any other element) is a substance in which the outer electron shell of each atom is completely filled. In an element that is not chemically inert, one or more electrons are missing from the outer shell. An atom with only one or two electrons in its outer shell can be made to give up those electrons; an atom whose outer shell needs only one or two electrons to be completely filled can accept electrons from another element which has one or two "extras."

The concept of "needed" or "extra" electrons arises from the basic fact that all atoms have a tendency toward completion (filling) of the outer shell. An atom whose outer shell has only two electrons would have to collect six additional ones (no easy task, from an energy standpoint) in order to have the eight required for a full shell. A much easier way to achieve the same objective is to give up the two electrons in the outer shell and let the full shell next to it serve as the new outer shell. In chemical terminology, this concept is called valence, and is the prime determining factor in predicting chemical combinations.

COMPOUNDS AND MIXTURES

Under certain conditions, two or more elements can be brought together in such a way that they unite chemically to form a COMPOUND. The resulting substance may differ widely from any of its component elements; for example, ordinary drinking water is formed by the chemical union of two gases—hydrogen and oxygen. When a compound is produced, two or more atoms of the combining elements join chemically to form the MOLECULE that is typical of the new compound. The molecule is the smallest unit that exhibits the distinguishing characteristics of a compound.

The combination of sodium and chlorine to form the chemical compound sodium chloride (common table salt) is a typical example of the formation of molecules. Sodium is a highly caustic poisonous metal containing eleven electrons; its outer shell consists of a single electron, which may be considered "extra" (a valence of + 1). Chlorine, a highly poisonous gas with seventeen electrons, "lacks" a single electron (has a valence of -1) to fill its outer shell. When the atom of sodium gives up its extra electron, it becomes a positively charged ion. (It has lost a unit of negative charge.) The chlorine, having taken on this extra unit of negative change (electron) to fill its outer shell, becomes a negative ion. Since opposite electric charges attract, the ions stick together to form a molecule of the compound sodium chloride.

The attracting force which holds the ions together in the molecular form is known as the "valence bond," a term which is frequently encountered in the study of transistors.

Note that in the chemical combination, there has been no change in the nucleus of either atom; the only change has occured in the distribution of electrons between the outer shells of the atoms. Also note that the total number of electrons has not changed—there are still the twenty-eight of the original two atoms—although there has been a slight redistribution. Therefore, the molecule is electrically neutral, and has no resultant electrical charge.

Not all chemical combinations of atoms are on a one-for-one basis. In the case of drinking water, two atoms of hydrogen (valence of + 1) are required to combine with a single atom of oxygen (valence of -2) to form a single molecule of water. Some of the more complex chemical compounds consist of many elements with various numbers of atoms of each. All molecules, like all atoms, are normally considered to be electrically neutral. There are some exceptions to this rule, however, with specific cases of interest being the chemical activity in batteries.

Elements or compounds may be physically combined without necessarily undergoing any chemical change. Grains of finely powered iron and sulfur stirred and shaken together retain their own identity as iron or sulfur. Salt dissolved in water is not a compound; it is merely salt dissolved in water. Each chemical substance retains its chemical identity, even though it may undergo a physical change. This is the typical characteristic of a MIXTURE.

STATES OF MATTER

In their natural condition, forms of matter are classified and grouped in many different ways. One such classification is in accordance to their natural state—solid, liquid, or gas. This classification is important because of the common characteristics possessed by substances in one group which distinguish them from substances in the other groups. However, the usefulness of the classification is limited by the fact that most substances can be made to assume any of the three forms.

In all matter, the molecules are assumed to be in constant motion, and it is the extent of this motion that determines the state of matter. The moving molecular particles in all matter possess kinetic energy of motion. The total of this kinetic energy is considered to be the equivalent of the quantity of heat in a sample of the substance. When heat is added, the energy level is increased, and molecular agitation (motion) is increased. When heat is removed, the energy level decreases, and molecular motion diminishes.

In solids, the motion of the molecules is greatly restricted by the rigidity of the crystalline structure of the material. In liquids, the molecular motion is somewhat less restricted, and the substance as a whole is permitted to "flow." In gases, molecular motion is almost entirely random—the molecules are free to move in any direction and are almost constantly in collision both among themselves and with the surfaces of the container.

This topic and some of its more important implications are discussed in detail under the heading "Heat" in a later section of this chapter.

Solids

The outstanding characteristic of a solid is the tendency to retain its size and shape. Any change in these values require the exchange of energy. The common properties of a solid are cohesion and adhesion, tensile strength, ductility, malleability, hardness, brittleness, and elasticity. Ductility is a measure of the ease with which the material can be drawn into a wire. Malleability refers to the ability of some materials to assume a new shape when pounded. Hardness and brittleness are self-explanatory terms. The remaining properties are discussed in more detail in the following paragraphs.

COHESION AND ADHESION.–Cohesion is the molecular attraction between like particles throughout a body, or the force that holds any substance or body together. Adhesion is the molecular attraction existing between surfaces of bodies in contact, or the force which causes unlike materials to stick together.

Cohesion and adhesion are possessed by different materials in widely varying degree. In general, solid bodies are highly cohesive but only alightly adhesive. Fluids (liquids and gases), on the other hand, are usually quite highly adhesive but only slightly cohesive. Generally a material having one of these properties to a high degree will possess the other property to a relatively low degree.

TENSILE STRENGTH.–The cohesion between the molecules of a solid explains the property called tensile strength. This is a measure of the resistance of a solid from being pulled apart. Steel possesses this property to a high degree, and is thus very useful in structural work. When a break does occur, the pieces of the solid cannot be stuck back together because merely pressing them together does not bring the molecules into close enough contact to restore the molecular force of cohesion. However, melting the edges of the break (welding) allows the molecules on both sides of the break to flow together, thus bringing them once again into the close contact required for cohesion.

ELASTICITY.–If a substance will spring back to its original form after being deformed, it has the property of elasticity. This property is desirable in materials to be used as springs. Steel and bronze are examples of materials which exhibit this property.

Elasticity of compression is exhibited to some degree by all solids, liquids, and gases; the closeness of the molecules in solids and liquids makes them hard to compress, but gases are easily compressed because the molecules are farther apart.

Liquids

The outstanding characteristic of a liquid is its tendency to retain its own volume while assuming the shape of its container; thus a liquid is considered almost completely flexible and highly fluid.

Liquids are practically incompressible; applied pressure is transmitted through them instantaneously, equally, and undiminished to all points on the enclosing surfaces. Hydraulic apparatus can be used to increase or to decrease input forces, thus providing an action similar to that of mechanical advantage in mechanical systems. Because of these properties, hydraulic servomechanisms have advantages as well as disadvantages and limitations when compared with other systems.

The fluidity of hydraulic liquids permits the component parts of the system to be placed conveniently at widely separated points when necessary. Hydraulic power units can transmit energy around corners and bends without the use of complicated gears and levers. They operate with a minimum of slack and friction, which are often excessive in mechanical linkages. Uniform action is obtained without vibration, and the operation of the system remains largely unaffected by variations in load. The accumulator (which provides the necessary pressurization of the system to furnish practically instantaneous response) can be pressurized during periods of nonaction, thus eliminating the "buildup time" characteristic of electric servos.

However, the hydraulic hoses which transmit the fluid from unit to unit are bulky and heavy compared to electric wiring. Many of the hydraulic fluids in common usage are messy and constitute safety hazards. They contribute to the danger of slipping, they cause deterioration of the insulation on electric wiring, they conduct electricity and thus increase the hazards of short circuiting, and they are flammable.

Rate Training Manual, Fluid Power, NavPers 16193-A, contains considerable detail on the basic theory of hydraulic systems and units.

Gases

The most notable characteristics of a gas are its tendency to assume not only the shape but also the volume of its containers, and the definite relationship that exists between the volume, pressure, and temperature of a confined gas.

The ability of a gas to assume the shape and volume of its container is the result of its extremely active molecular particles, which are free to move in any direction. Cohesion between molecules of a gas is extremely small, so the molecules tend to separate and distribute themselves uniformly throughout the volume of the container. In an unpressurized container of liquid, pressure is exerted on the bottom and the sides of the container up to the level of the liquid. In a gas, however, the pressure is also exerted against the top surface, and the pressure is equal at all points on the enclosing surfaces.

The relationship of volume, pressure, and temperature of a confined gas are explained by Boyle's law, Charles' law, and the general law for gases.

Many laboratory experiments based on these laws make use of the ideas of "standard pressure" and "standard temperature." These are not natural standards, but are standard values selected for convenience in laboratory usage. Standard values are generally used at the beginning of an experiment, or when a temperature or a pressure is to be held constant. Standard temperature is 0° C, the temperature at which pure ice melts. Standard pressure is the pressure exerted by a column of mercury 760 millimeters high. In many practical uses these standards must be changed to other systems of measurement.

All calculations based on the laws of gases make use of "absolute" temperature and pressure. These topics require a somewhat more detailed explanation.

GAS PRESSURE.–Gas pressure may be indicated in either of two ways–absolute pressure or gage pressure. Since the pressure of an absolute vacuum is zero, any pressure measured with respect to this reference is referred to as "absolute pressure." In the present discussion, this value represents the actual pressure exerted by the confined gas.

At sea level the average atmospheric pressure is approximately 14.7 pounds per square inch (psi). This pressure would, in a mercuirial barometer, support a column of mercury 760 millimeters in height. Thus, normal atmospheric pressure is the standard pressure mentioned previously.

However, the actual pressure at sea level varies considerably; and the pressure at any given altitude may differ from that at sea level. Therefore, it is necessary to take into consideration the actual atmospheric pressure when converting absolute pressure to gage pressure (or vice versa).

When a pressure is expressed as the difference between its absolute value and that of the local atmospheric pressure, the measurement is designated "gage" pressure, and is usually expressed in "pounds per square inch gage" (psig). Gage pressure may be converted to absolute pressure by adding the local atmospheric pressure to the gage pressure.

ABSOLUTE ZERO.–Absolute zero, one of the fundamental constants of physics, is usually expressed in terms of the centigrade scale. Its most predominant use is in the study of the kinetic theory of gases. In accordance with the kinetic theory, if the heat energy of a given gas sample could be progressively reduced, some temperature should be reached at which the motions of the molecules would cease entirely. If accurately determined, this temperature could then be taken as a natural reference, or a true "absolute zero" value.

Experiments with hydrogen (making use of the proven correlation with the volume, temperature, and pressure of gases and by calculations based on this correlation) indicated that if a gas were cooled to -273.16° C (used as -273° for most calculations), all molecular motion would cease and no additional heat could be extracted from the substance. At this point both the volume and the pressure would shrink to zero.

When temperatures are measured with respect to the absolute zero reference, they are said to be expressed in the absolute, or Kelvin, scale. Thus, absolute zero may be expressed either as 0° K or as -273° C.

BOYLE'S LAW.–The English scientist Robert Boyle was among the first to study what he called the "springiness of air." By direct measurement he discovered that when the temperature of an enclosed sample of gas was kept constant and the pressure doubled, the volume was reduced to half the former value; as the applied pressure was decreased, the resulting volume increased. From these observations, he concluded that for a constant temperature the product of the volume and pressure of an enclosed gas remains constant. Boyle's law is normally stated: "The volume of an enclosed dry gas varies inversely with its pressure, provided the temperature remains constant."

In equation form, this relationship may be expressed either

$$V_1P_1 = V_2P_2, \text{ or}$$

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

where V_1 and P_1 are the original volume and pressure, and V_2 and P_2 are the revised volume and pressure.

CHARLES' LAW.–The French scientist Jacques Charles provided much of the foundation for the modern kinetic theory of gases. He found that all gases expand and contract in direct proportion to the change in the absolute temperature, provided the pressure is held constant. Expressed in equation form, this part of the law may be expressed

$$V_1T_2 = V_2T_1, \text{ or}$$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

where V_1 and V_2 refer to the original and final volumes, and T_1 and T_2 indicate the corresponding absolute temperatures.

Since any change in the temperature of a gas causes a corresponding change in volume, it is reasonable to expect that if a given sample of a gas were heated while confined within a given volume, the pressure should increase. By actual experiment, it was found that the increase in pressure was approximately 1/273 of the 0° C pressure for each 1° C increase. Because of this fact, it is normal practice to state this relationship in terms of absolute temperature. In equation form, this part of the law becomes

$$P_1T_2 = P_2T_1, \text{ or}$$

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

In words, this equation states that with a constant volume, the absolute pressure of a gas varies directly with the absolute temperature.

GENERAL GAS LAW.–The facts concerning gases discussed in the preceding sections are summed up and illustrated in figure 5-2. Boyle's law is expressed in (A) of the figure; while the effects of temperature changes on pressure and volume (Charles' law) are illustrated in (B) and (C), respectively.

By combining Boyle's and Charles' laws, a single expression can be derived which states all the information contained in both. This expression is called the GENERAL GAS EQUATION, a very useful form of which is given by the following equation. (NOTE: The capital P and T signify absolute pressure and temperature, respectively.)

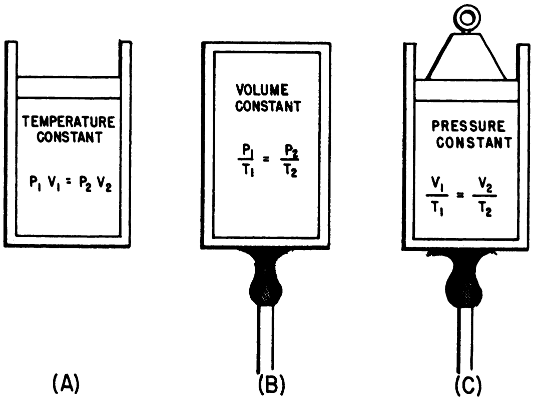


Figure 5-2.–The general gas law.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

It can be seen by examination of figure 5-2 that the three equations are special cases of the general equation. Thus, if the temperature remains constant, T_1 equals T_2 and both can be eliminated from the general formula, which then reduces to the form shown in (A). When the volume remains constant, V_1 equals V_2, thereby reducing the general equation to the form given in (B). Similarly, P_1 is equated to P_2 for constant pressure, and the equation then takes the form given in (C).

The general gas law applies with exactness only to "ideal" gases in which the molecules are assumed to be perfectly elastic. However, it describes the behavior of actual gases with sufficient accuracy for most practical purposes.

MECHANICS

Mechanics is that branch of physics which deals primarily with the ideas of force, mass, and motion. Normally considered the fundamental branch of physics, it deals with matter. Many of its principles and ideas may be seen, measured, and tested. Since all other branches of physics are also concerned (to some extent at least) with force, mass, and motion, a thorough understanding of this section will aid in the understanding of later sections of this chapter.

FORCE, MASS, AND MOTION

Each particle in a body is acted upon by gravitational force. However, in every body there is one point at which a single force, equal to the gravitational force and directed upward, would sustain the body in a condition of rest. This point is known as the CENTER OF GRAVITY, and represents the point at which the entire mass of the body appears to be concentrated. The gravitational effect is measured from the center of gravity. In symmetrical objects of uniform mass, this is the geometrical center. In the case of the earth, the center of gravity is near the center of the earth.

When considering the motion of a body, it is usually convenient to describe the path followed by the center of gravity. The natural tendency of a moving body is to move in a manner so that the center of gravity travels in a straight line. Movement of this type is called LINEAR motion.

Some moving bodies, however, do not move in a straight line, but describe an arc or a circular path. Circular motion falls into two general classes–rotation and revolution.

Since objects come in many different shapes and in order to discuss rotary and revolutionary motion, it becomes necessary to consider the location of the center of gravity with respect to the body. (Refer to figure 5-3 for the following discussion.)

In (A), the center of gravity of a ball coincides with the physical center of the ball. However, in the flat washer (B), the center of gravity does not coincide with any part of the object, but is located at the center of the hollow space inside the ring. In irregularly shaped bodies, the center of gravity may be difficult to locate exactly.

If the body is completely free to rotate, the center of rotation coincides with the center of gravity. On the other hand, the body may be restricted in such a manner that rotation is about some point other than the center of gravity. In this event, the center of gravity revolves around the center of rotation. This condition is illustrated in figure 5-4.

In general usage, the gyro rotor (A) is said to ROTATE about its axis, and the ball (B) is said to REVOLVE about a point at the center of its path.

MASSES IN MOTION

Any change in the speed or direction of motion of a body is known as acceleration and requires the application of some force. The acceleration of a body is directly proportional to the force causing that acceleration; acceleration depends also upon the mass of the body. The greater mass of a lead ball makes it harder to move than a wood ball of the same diameter. The wood ball moves farther with the same push.

These observations point to a connection between force, mass, and acceleration, and indicate that the acceleration of a body is directly proportional to the force exerted on that body and inversely proportional to the mass of that body. In mathematical form, this relationship may be expressed as

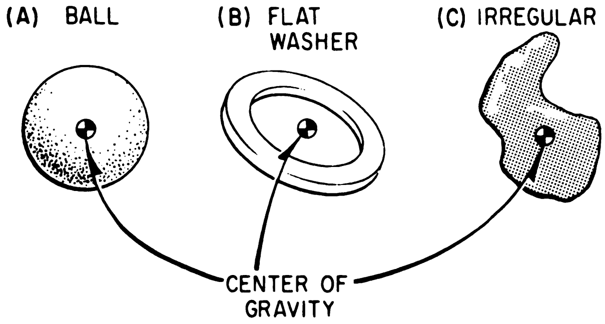


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Figure 5-3.–Center of gravity in various bodies.

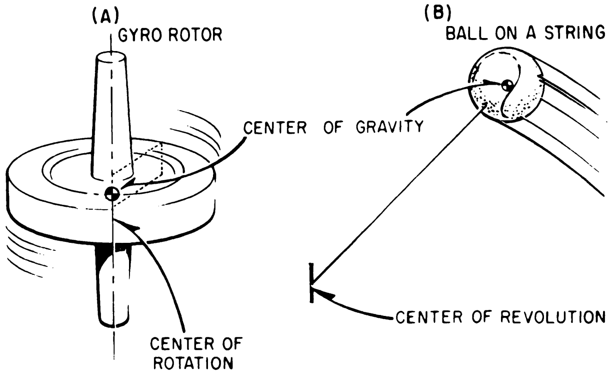

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Figure 5-4.–Center of gravity of rotation.

$$a = \frac{F}{m}$$

or, as it is more commonly stated: Force is equal to the product of the mass and acceleration (F = ma).

If the accelerating force is applied to the center of gravity in such a manner as to accelerate the body with no rotation, it is called a TRANSLATIONAL force. A force applied in such a manner as to cause the body to rotate about a point is called a TORQUE force.

Laws of Motion

Among the most important discoveries in theoretical physics are the three fundamental laws of motion attributed to Newton. Although some of these laws have been used in explanations of various topics earlier in this chapter, they are restated and consolidated at this point to clarify and summarize much of the discussion regarding mechanical physics. This restatement and consolidation are also used to introduce additional aspects involving the applications of basic mechanical principles.

1. Every body tends to maintain a state of uniform motion unless a force is applied to change the speed or direction of motion.
2. The acceleration of a body is directly proportional to the magnitude of the applied force and inversely proportional to the mass of the body; acceleration is in the direction of the applied force.
3. For every force applied to a body, the body exerts an equal force in the opposite direction.

Momentum

Every moving body tends to maintain uniform motion. Quantitative measurement of this tendency is proportional to the mass of the body, and also to its velocity.
(Momentum = mass x velocity.) This explains why heavy objects in motion at a given speed are harder to stop than lighter objects, and also why it is easier to stop a given body moving at low speed than it is to stop the same body moving at high speed.

WORK, POWER, AND ENERGY

As defined earlier, energy is the capacity for doing work. In mechanical physics, WORK involves the idea of a mass in motion, and is usually regarded as the product of the applied force and the distance through which the mass is moved (work = force x distance). Thus, if a man raises a weight of 100 pounds to a height of 10 feet he accomplishes 1,000 foot-pounds of work. The amount of work accomplished is the same regardless of the time involved. However, the RATE of doing the work may vary greatly.

The rate of doing work (called POWER) is defined as the work accomplished per unit of time (power = work/time). In the example cited above, if the work is accomplished in 10 seconds, power is being expended at the rate of 100 foot-pounds per second; if it takes 5 minutes (300 seconds), the rate is approximately 3.3 foot-pounds per second.

In the English system of measurements, the unit of mechanical power is called the HORSEPOWER and is the equivalent of 33,000 foot-pounds per minute, or 550 foot-pounds per second. Since energy is readily convertible from one form to another, the work and power measurements based on the conversion of energy must also be readily convertible. As an example, the electrical unit of power is the watt. Electrical energy may be converted into mechanical energy; therefore, electrical power must be convertible into mechanical power. One horsepower is the mechanical equivalent of 746 watts of electrical power, and is capable of doing the same amount of work in the same time.

The accomplishment of work always involves a change in the type of energy, but does not normally change the total quantity of energy. Thus, energy applied to an object may produce work, changing the composition of the energy possessed by the object. When the work stops, energy is no longer being "expended," so energy must once again be converted in form—but not necessarily into its original form.

Efficiency

Provided there is no change in the quantity of matter, energy is convertible with no gain or loss. However, the energy resulting from a given action may not be in the desired form—it may not even be usable in its resultant form. In all branches of physics, this concept is known as EFFICIENCY.

The energy expended is always greater than the energy recovered. An automobile in motion possesses a quantity of kinetic energy dependent on its mass and velocity. In order to stop the car, this energy must be converted into potential energy. When the car is at rest, its potential energy is considerably less than the kinetic energy it possessed while in motion. The difference, or the "energy lost" is converted into heat by the brakes. The heat serves no useful purpose, so the recovered energy is less than the expended energy—the system is less than 100 percent efficient in converting kinetic to potential energy.

The term efficiency is normally used in connection with work and power considerations to denote the ratio of the input to the output work, power, or energy. It is always expressed as a decimal or as a percent less than unity.

Friction

In mechanical physics, the most common cause for the loss of efficiency is FRICTION. Whenever one object is slid or rolled over another, irregularities in the contacting surfaces interlock and cause an opposition to the force being exerted. Even rubbing two smooth pieces of ice together produces friction, although of a much smaller magnitude than in the case of two rough stones. Friction also exists in the contact of air with all exposed parts of an aircraft in flight, as well as in the brakes of the automobile mentioned above.

When a nail is struck with a hammer, the energy of the hammer is transferred to the nail, and the nail is driven into a board. The depth of penetration depends on the momentum of the hammer, the size and shape of the nail, and the hardness of the wood. The larger or duller the nail and the harder the wood, the greater the friction, and therefore the lower the efficiency and less depth of penetration—but the greater the heating of the nail.

Friction is always present in moving machinery, and accounts in part for the fact that the useful work accomplished by the machine is never as great as the energy applied. Work accomplished in overcoming friction is usually not recoverable. Friction can be minimized by decreasing the number of contacting points, by making the contacting areas as small and as smooth as possible, by the use of bearings, or by the use of lubricants.

There are two kinds of friction—sliding and rolling, with rolling friction usually of lower magnitude. Therefore, most machines are constructed so that rolling friction is present rather than sliding friction. The ball bearing and the roller bearing are used to convert sliding friction to rolling friction. A third type, the common (or friction) bearing, utilizes lubricants applied to surfaces which have been made as smooth as possible. Many new types of machines utilize self-lubricating bearings to minimize friction and thus maximize efficiency.

Mechanical Advantage

The concept of mechanical advantage has proved to be one of the great discoveries of science. It permits an increase in force or distance and represents the basic principle involved in levers, block and tackle systems, screws, hydraulic mechanisms, and other work saving devices. However, in the true sense, these devices do not save work, they merely enable humans to accomplish tasks which might otherwise be beyond their capability. For example, a human would normally be considered incapable of lifting the rear end of a truck in order to change a tire; but with a jack, a block and tackle, or a lever, the job can be made comparatively easy.

Mechanical advantage is usually considered with respect to work. Work represents the application of a force through a distance in order to move an object through a distance. Thus, it may be seen that there are two forces involved, each with an appropriate distance. This is illustrated by the simple lever in figure 5-5.

Assuming perfect efficiency, the work input (F_1D_1) is equal to the work output (F_2D_2). Assuming equal distances D_1 and D_2, a force of 10 pounds must be applied at the source in order to counteract a weight of 10 pounds at the load.

By moving the fulcrum nearer the load, less force is required to balance the same load. This is a mechanical advantage of force. If the force is applied in such a manner as to raise the

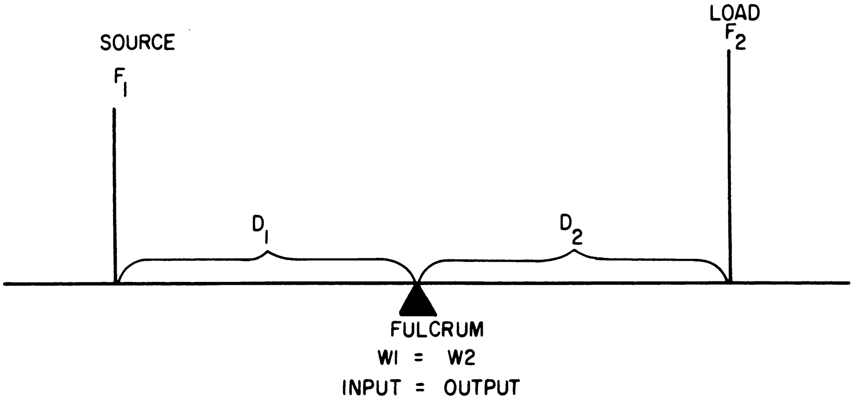

Figure 5-5.–Mechanical advantage.

load 1 foot, the source must be moved through a distance greater than 1 foot. Thus, mechanical advantage of force represents a mechanical disadvantage of distance. By moving the fulcrum nearer the source, these conditions are reversed.

Since the input work equals the output work (assuming no losses), the mechanical advantage may be stated as a ratio of the force or of the distances. In actual situations, friction results in energy loss and decreased efficiency, thereby requiring an even greater input to accomplish the same work.

A more detailed discussion of mechanical advantages and the characteristics of the six basic mechanical devices (the lever, the screw, the inclined plane or wedge, the block and tackle, the wheel and axle, and the gear) is found in the Rate Training Manual, Basic Machines, NavPers 10624-A.

REVOLVING BODIES

Revolving bodies represent masses in motion; therefore, they possess all the characteristics (and obey all the laws) associated with moving bodies. In addition, since they possess a specific type of motion, they have special properties and factors which must be taken into consideration.

Revolving bodies travel in a constantly changing direction, so they must be constantly subjected to an accelerating force. Momentum tends to produce linear motion, but this is prevented by application of a force which restrains the object. This restraining force prevents the object from continuing in a straight line, and is known as CENTRIPETAL force. According to Newton's third law of motion, the centripetal force must be opposed by an equal force which tends to produce linear motion. This second force is known as CENTRIFUGAL force. The two forces, their relationships, and their effects are illustrated in figure 5-6 and the following explanatory example.

The various forces involved in revolving bodies may be illustrated by use of a ball and string. A slip knot is tied in the center of a 10-foot length of twine so as to shorten the line to 5 feet; a rubber ball is attached to one end of the string. Holding the other end of the line, whirl the ball slowly in a circle. Note that the ball exerts a force against the hand (through the string); and that in order to restrain the ball in its circular path, the hand must exert a force (through the string) on the ball. As the ball is revolved at higher speed, the forces increase, and the ball continues in a circular path. As the rotational velocity of the ball is gradually increased, note the increasing forces.

At some rotational speed, the forces involved become great enough to overcome inertial friction, and the knot slips. At this time, allow the velocity of the rotation to stabilize (stop increasing in rotational velocity, but not slowing down, either), so that the existing conditions may be analyzed. When the knot slips, the ball is temporarily unrestrained and is free to assume linear motion in the direction of travel at that instant (tangent to the circle at the instantaneous position). The ball travels in a straight line until the string reaches its full length;

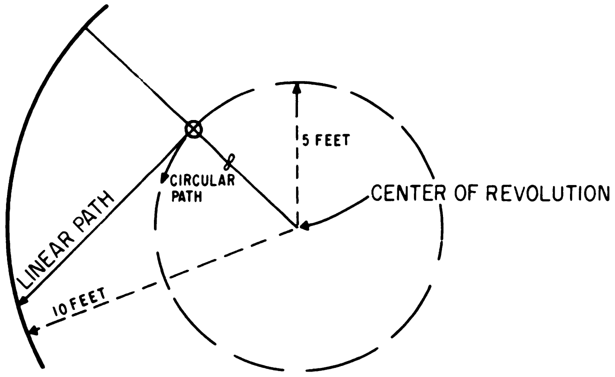

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Figure 5-6.—Forces on revolving bodies.

during this time, no force is exerted on or by the hand. As soon as all the slack is taken up, there is a sharp jerk—an accelerating force is exerted in order to change the direction of motion from its linear path into a circular rotation. The ball again assumes rotational motion, but with an increase in radius.

The ball does not make as many revolutions in the same time (rotational velocity is decreased), but it does maintain its former linear velocity. (The kinetic energy and the momentum of the ball have not changed.) Since the change in direction is less abrupt with a large radius than with a small one, less accelerating force is required, and the hand will feel less force. If the ball is then accelerated to the same rotational velocity as immediately prior to the slipping of the knot, the linear velocity of the ball becomes much greater than before; the centripetal and centrifugal forces are much greater, also.

In this example, it has been assumed that the hand is fixed at a point which represents the center of rotation. This assumption, while somewhat erroneous, does not affect the general conclusions. For practical purposes, the two forces are equal at all points along the string at any given time, and the magnitude of each force is equal at all points along the string.

In summarizing the conclusions reached by the above example and explanation, consider the following relationship:

$$\text{force} = \frac{\text{mass x velocity}^2}{\text{radius}}$$

where velocity represents the linear velocity of the ball. This emphasizes that the centripetal and the centrifugal forces are equal in magnitude and opposite in direction. Each force is directly proportional to the mass of the body and inversely proportional to the radius of rotation. Each force is also proportional to the square of the velocity.

In revolving or rotating bodies, all particles of the matter which are not on the axis of rotation are subjected to the forces just described. The statement is true whether the motion is through a complete circle, or merely around a curve: An aircraft tends to skid when changing course; an automobile tends to take curves on two wheels. The sharper the curve (smaller radius) or the higher the velocity, the greater the tendency to skid.

WAVE MOTION

Wave motion and radiated energy may be compared with the wave motion of water. When a pebble is dropped into a calm pool of water, a series of circular waves travel away from the disturbance. These waves radiate in all directions on the surface of the water until they are absorbed or until they are diverted by coming into contact with an obstruction of some sort. Water waves are a succession of crests and troughs; the distance from the crest of one wave to the crest of the next is called the wavelength. A cork floating on the surface of the water bobs up and down with the waves, but moves very little in the direction of wave travel. Water waves are called transverse waves because the motion of the water particles is up and down, or at right angles (transverse) to the direction in which the wave is traveling.

A second form of wave motion, also involving the motion of particles of matter, may be produced by the physical vibration of a body. An example of this type wave is the sound wave which is produced by striking the tine of a tuning fork. When struck, the tuning fork sets up a vibratory motion. As the tine moves in an outward direction, the air immediately in front of the tine is compressed so that its momentary pressure is raised above that at other points in the surrounding medium. Because air is elastic, this disturbance is transmitted progressively in an outward direction as a compression wave.

When the tine returns and moves in the inward direction, the air in front of the tine is rarefied so that its momentary pressure is reduced below that at other points in the surrounding medium. This disturbance is also propagated, but in the form of a rarefaction (expansion) wave, and follows the compression wave through the medium.

The compression and expansion waves are also called longitudinal waves, because the particles of matter which comprise the medium move back and forth longitudinally in the direction of wave travel. Figure 5-7 is a simplified representation of the use of a tuning fork to produce a longitudinal wave. The transverse wave shown below the longitudinal wave is merely a convenient device to indicate the relative density of the particles in the medium, and does not reflect the movement of the particles.

The progress of any wave requiring movement of particles in the transmission medium involves two distinct motions: the wave itself moves forward with constant speed, and simultaneously the particles within the medium vibrate. The period of a vibrating particle is the time (t, in seconds) required for the particle to complete one full vibration or cycle. The frequency (f) is the number of vibrations completed per unit of time and is usually expressed in Hertz. The period is the reciprocal of the frequency ($t = 1/f$). The amplitude of vibration is the maximum variation of particle density from the equilibrium density.

A body vibrating at a definite rate produces a disturbance that moves away as a wave in the surrounding medium. The velocity of this wave is equal to the wavelength divided by the period. Since the period is the reciprocal of the frequency, the velocity may be expressed as

$$v = f\lambda$$

where v is the velocity of propagation of the wave in the given medium, f is the frequency in Hertz, and λ is the wavelength in compatible units of measure. The velocity of propagation may also be described as representing the distance that a wave travels during one period.

Two particles are in phase when they are vibrating with the same frequency, and continually pass through corresponding points of their paths at the same time. For any other condition, the particles are out of phase. Two particles are in phase opposition when they reach their maximum displacements in opposite directions at the same time.

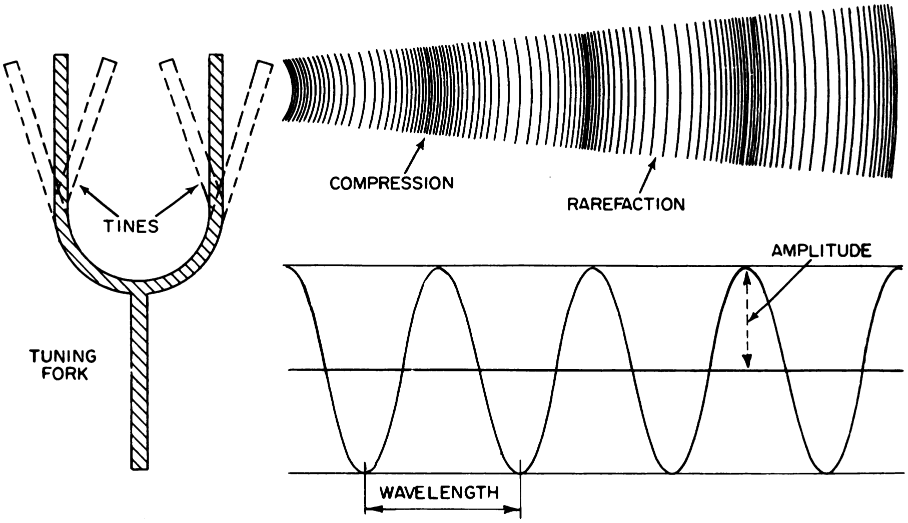

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Figure 5-7.–Compression and expansion wave propagation.

A third type of wave, the electromagnetic wave, does not involve moving particles of matter, but rely on electric and magnetic force fields. The waves previously discussed cannot be propagated in the absence of a conducting medium—electromagnetic waves are propagated most efficiently in the absence of matter. In the electromagnetic wave, two components are required—an electric field and a magnetic field. These two fields are mutually perpendicular to each other and to the direction of propagation. In the particle waves, the velocity of propagation varies with the particular medium, and is comparatively very slow; in the electromagnetic wave, the velocity of propagation is the speed of light (approximately 186,300 miles per second). Examples of electromagnetic waves include heat, light, radio waves, X-rays, cosmic radiations, ultraviolet rays, etc.

All three types of wave motion obey certain common laws and have certain common characteristics: All are periodic; that is, they all constantly repeat the same pattern so that each succeeding wave is the same as the previous one. Each wave displays the same relationships of wavelength, frequency, period, velocity of propagation, amplitude, and phase; and each is subject to the same conditions of reflection and refraction. In the electromagnetic wave, the maxima and minima are correlated with field intensity rather than with particle density or displacement as in the case of the other waves. In the longitudinal wave, the density is related to particle density; in the electromagnetic wave, density is related to the strength of the electric and magnetic fields. In the electromagnetic wave, the electric field and the magnetic field are in phase with each other.

A wavelength is the distance measured along the axis of propagation between two corresponding points of equal intensity which are in phase on adjacent waves. This length can be represented by the distance between maximum points on successive waves.

A line drawn from the source to any point on one of the waves is called a RAY, and indicates the path over which the wave progresses.Although rays do not actually exist, they are frequently used in illustrations as a convenient method of denoting wave propagation. A wavefront is a surface on which all points are in phase. Wavefronts near the source are sharply curved, while those at a distance are almost flat; individual rays from a distant source are considered to be parallel.

REFLECTION

Within a uniform medium, a ray travels in a straight line. Only at the boundary of two media or in an area where the density of the medium changes do the rays change their direction. When an advancing wavefront encounters a medium of different characteristics, some of its energy is reflected back into the initial medium, and some is transmitted into the second medium. When a wavefront encounters a medium which it cannot penetrate, the wave is reflected from the surface.

REFLECTED waves are simply those waves that are neither transmitted nor absorbed, but are thrown back from the surface of the medium they encounter. If a ray is directed against a reflecting surface, the ray striking the surface is called the INCIDENT ray, and the one that bounces back is the REFLECTED ray. An imaginary line perpendicular to the reflecting surface at the point of impact of the incident ray is called the NORMAL. The angle between the incident ray and the normal is called the ANGLE OF INCIDENCE; the angle between the reflected ray and the normal is the ANGLE OF REFLECTION. These terms are illustrated in figure 5-8.

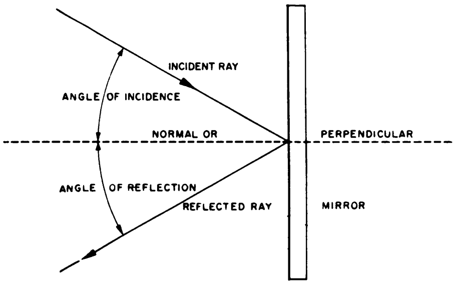

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Figure 5-8.—Terms used to describe the reflection of waves.

If the surface of the medium contacted by the incident ray is smooth and polished (as a mirror), each reflected ray will be thrown back at the same angle as the incident ray. The path of the ray reflected from the surface forms an angle exactly equal to the one formed by its path in reaching the medium. This conforms to the law of reflection which states: The angle of incidence is equal to the angle of reflection.

Diffusion

Reflection from a relatively smooth surface presents few problems. As shown in figure 5-9 (A), rays are reflected from a flat smooth surface in an orderly manner with all rays at the same angle and all rays parallel to each order. This is called regular or specular reflection. It is a different matter, however, with a rough surface. The law of reflection is still valid; but due to the rough surface, the angle of incidence is somewhat different for each ray. The reflected rays scatter in all directions, as shown in figure 5-9 (B). This form of reflection is called irregular or diffused reflection.

Focusing

In addition to reflection from a flat surface and diffusion from a rough one, waves may also be focused by reflection from a curved surface. If the reflecting surface is concave, the parallel rays striking its surface are reflected, as shown in figure 5-10 (A). The normal is perpendicular to the surface; therefore, the normals on a curved surface are not parallel to one another. The rays come together, or converge, at some point called the focal point. The location of the focal point depends on the rate of curvature of the reflecting surface.

Illumination

If a point source of waves is located at the focal point of the concave reflector, the reflected rays are formed into a narrow beam, with all reflected rays parallel to one another.

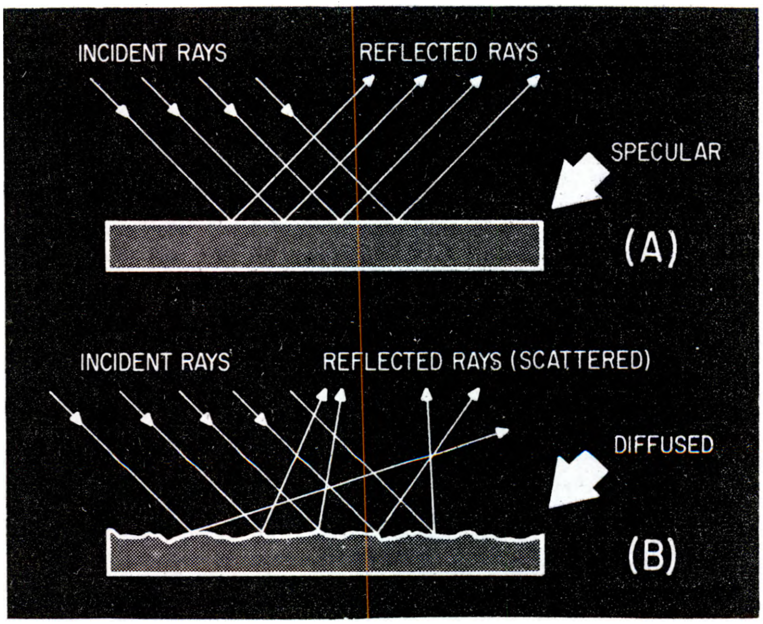

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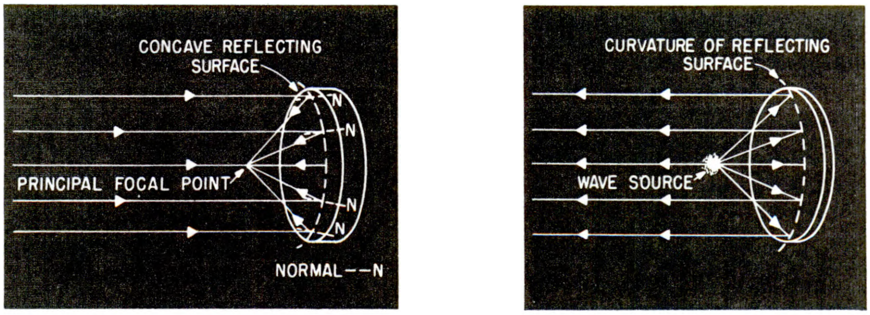
Figure 5-9.–Reflection from a plane surface. (A) Regular (specular); (B) irregular (diffused).



(A) (B)

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Figure 5-10.–Reflection from a concave surface. (A) Focusing; (B) illumination.

This condition is illustrated in figure 5-10 (B). In this manner, the intensity is increased (or the area is "illuminated"), because rays that would normally be lost are directed into the beam along with the direct rays.

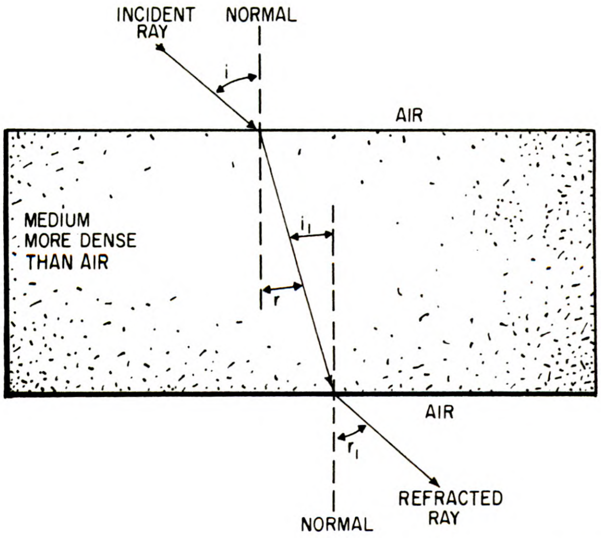
REFRACTION

The change of direction which occurs when a ray passes from one medium into another of different density is called REFRACTION. It is due to the fact that waves travel at various speeds in different transmission media. Refraction always follows a general rule: When a ray passes from one medium into another of greater density, refraction is toward the normal; when passing into a medium of lesser density, refraction is away from the normal. This is illustrated in figure 5-11.

DOPPLER EFFECT

When there is relative motion between the source of a wave and a detector of that wave, the apparent frequency at the terminal position differs from the frequency at the source. If the distance between the source and the detector is decreasing, more wavefronts are encountered per second than when the distance is constant. This results in an apparent increase in frequency. Conversely, if the separation is increasing, fewer waves are encountered, with an apparent decrease in frequency.

These apparent changes in frequency are called the Doppler effect, and affect the operation of equipment used to detect and measure wave energy. The amount of change in the apparent frequency depends on the relative velocity of the source and detector and on the velocity of propagation of the wave. The Doppler effect is important in dealing with sound wave propagation as applicable to sonar equipment operation, and in dealing with electromagnetic wave propagation as applicable to radar search, target detection, fire control,



AT.30

Figure 5-11.—Refraction of a wave.

navigation, etc. Specific applications of the Doppler effect are not discussed in detail in this chapter.

HEAT

Heat represents a form of energy; therefore, it must be readily exchangeable with or convertible into, other forms of energy. The conversion of mechanical energy into heat through friction has been mentioned previously. When a piece of lead is struck a sharp blow with a hammer, part of the kinetic energy of the hammer is converted into heat. In the core of a transformer, electrical and magnetic energy are exchanged; but due to hysteresis and eddy currents, some of the energy is lost as heat. These are some examples of the unwanted conversions, but there are many instances when the production of heat is desirable. Many devices are used almost exclusively to produce heat.

Regardless of how or why it is produced, heat possesses certain characteristics which make it important to the technician. A knowledge of the nature and behavior of heat may prove helpful in understanding the operation of some types of electronics equipment or in determining the cause of nonoperation or faulty operation of others.

NATURE OF HEAT

There are several theories regarding the nature of heat, none of which satisfactorily explain all the characteristics and properties exhibited by heat. The two theories most commonly included in discussions regarding the nature of heat are the kinetic theory and the radiant energy theory.

In the kinetic theory (mentioned earlier in this chapter), it is assumed that the quantity of heat contained by a body is represented by the total kinetic energy possessed by the molecules of the body.

The radiation theory treats radio waves, heat, and light as the same general form of energy, differing primarily in frequency. Heat is considered as a form of electromagnetic energy involving a specific band of frequencies falling between the radio spectrum and light.

A common method used to produce heat energy is the burning process. Burning is a chemical process in which the fuel unites with oxygen, and a flame is usually produced. The amount of heat liberated per unit mass or per unit volume during complete burning is known as the heat of combustion of a substance. By experiment, scientists have found that each fuel produces a given amount of heat per unit quantity burned.

TRANSFER

There are three methods of heat transfer-conduction, convection, and radiation. In addition to these, a phenomenon called absorption is related to the radiation method.

Conduction

The metal handle of a hot pot may burn the hand; a plastic or wooden handle, however, remains relatively cool even though it is in direct contact with the pot. This phenomenon is due to a property of matter known as thermal conductivity. All materials conduct heat—some very readily, some to an almost negligible extent. When heat is applied to a body, the molecules at the point of application become violently agitated, strike the molecules next to them, and cause increased agitation. The process continues until the heat energy is distributed evenly throughout the material. Aluminum and copper are used for cooking pots because they conduct heat very readily to the food being cooked. Wood and plastic are used as handles because they are very poor conductors of heat. As a general rule metals are the best conductors of heat, although some metals are considerably better than others.

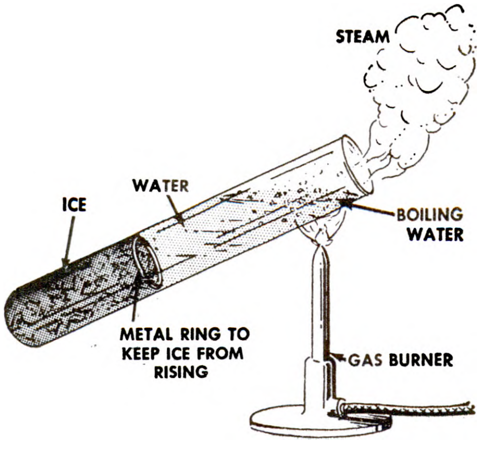
Among solids, there is an extreme range of thermal conductivity. In the original example, the metal handle transmits heat from the pot to the hand, with the possibility of burns. The wooden or plastic handle does not conduct heat very well, so the hand is given some protection. Materials that are extremely poor conductors are called "insulators" and are used to prevent heat transfer. Some examples are the wood handle of soldering irons, the finely spun glass or rock wool insulation in houses, or the asbestos tape or ribbon wrapping used on steam pipes.

Liquids are generally poorer conductors than metals. In figure 5-12, note that the ice in the bottom of the test tube has not yet melted, although the water at the top is boiling. Water is such a poor conductor that the rate of heating of the water at the top of the tube is not sufficient to cause rapid melting of the ice at the bottom.

Since thermal conduction is a process by which molecular energy is passed on by actual contact, gases are generally even poorer conductors than liquids because the molecules are farther apart and molecular contact is not so pronounced.

Convection

Convection is the process in which heat is transferred by movement of a hot fluid. For example, an electron tube gets hotter and hotter until the air surrounding it begins to move. The motion of the air is upward because heated air expands in volume and is forced upward by the denser cool air surrounding it. The upward motion of the heated air carries the heat away from the hot tube by convection. Transfer of heat by convection may be hastened by using a ventilating fan to move the air surrounding a hot object. The rate of cooling of a hot vacuum tube can also be increased by providing copper fins to conduct heat away from the hot tube. The fins provide large surfaces against which cool air can be blown.



AT.31

Figure 5-12.—Water is a poor conductor of heat.

A convection process may take place in a liquid as well as in a gas. One example is a transformer in an oil bath. The hot oil is less dense (has less weight per unit volume) and rises, while the cool oil falls, is heated, and rises in turn.

When the circulation of gas or liquid is not rapid enough to remove sufficient heat, fans or pumps may be used to accelerate the motion of the cooling material. In some installations, pumps are used to circulate water or oil to help cool large equipment. In airborne installations electric fans and blowers are used to aid convection.

Radiation

Conduction and convection cannot wholly account for some of the phenomena that are associated with heat transfer. For example, heating through convection cannot occur in front of an open fire because the air currents are moving toward the fire. It cannot occur through conduction because the conductivity of the air is very low, and the cooler currents of air moving toward the fire would more than overcome the transfer of heat outward. Therefore, heat must travel across space by some means other than conduction and convection.

The existence of another process of heat transfer is still more evident when the heat from the sun is considered. Since conduction and convection take place only through molecular contact within some medium, heat from the sun must reach the earth by some other method. (Outer space is an almost perfect vacuum.) Radiation is the name given to this third method by which heat travels from one place to another.

The term radiation refers to the continual emission of energy from the surface of all bodies. This energy is known as radiant energy. It is in the form of electromagnetic waves and is identical in nature with light waves, radio waves, and X-rays, except for a difference in wavelength. Sunlight is a form of radiant heat energy which travels great distances through cold, empty space to reach the earth. These electromagnetic heat waves are absorbed when they come in contact with nontransparent bodies.

The net result is that the motion of the molecules in the body is increased, as indicated by an increase in the temperature of the body.

The differences in conduction, convection, and radiation are as follows:

1. Although conduction and convection are extremely slow, radiation takes place with the speed of light. This fact is evident at the time of an eclipse of the sun when the shutting off of the heat from the sun takes place at the same time as the shutting off of the light.

2. Radiant heat may pass through a medium without heating it. For example, the air inside a greenhouse may be much warmer than the glass through which the sun's rays pass.

3. Although conducted or convected heat may travel in roundabout routes, radiant heat always travels in a straight line. For example, radiation can be cut off with a screen placed between the source of heat and the body to be protected.

Absorption

The sun, a fire, and an electric light bulb all radiate energy, but a body need not glow to give off heat. A kettle of hot water or a hot soldering iron radiates heat. If the surface is polished or light in color, less heat is radiated. Bodies which do not reflect are good radiators and good absorbers, and bodies that reflect are poor radiators and poor absorbers. This is the reason white clothing is worn in the summer. A practical example of the control of heat is the Thermos bottle. The flask itself is made of two walls of "silvered" glass with a vacuum between them. The vacuum prevents the loss of heat by conduction and convection and the "silver" coating prevents the loss of heat by radiation.

The silver-colored bronze paint on the "radiators" in heating systems is used only for decoration and decreases the efficiency of heat transfer. The most effective color for heat transfer is dull black; dull black is the ideal absorber and also the best radiator.

MEASUREMENT OF HEAT

A unit of heat must be defined as the heat necessary to produce some agreed-on standard of change. There are three such units in common use as follows:

1. One British thermal unit (Btu) is the quantity of heat necessary to raise the temperature of 1 pound of water 1° F.

2. One gram-calorie (small calorie) is the quantity of heat necessary to raise 1 gram of water 1° C.

3. One kilogram-calorie (large calorie) is the quantity of heat necessary to raise 1 kilogram of water 1° C. (One kilogram-calorie equals 1,000 gram-calories.) The gram-calorie or small calorie is much more widely used than the kilogram-calorie or large calorie. The large calorie is used in relation to food energy and for measuring comparatively large amounts of heat. Throughout this discussion, unless otherwise stated, the term calorie means gram-calorie. For purposes of conversion, one Btu equals 252 gram-calories or 0.252 kilogram-calories.

The terms quantity of heat and temperature are commonly misused. The distinction between them should be understood clearly. For example, suppose that two identical pans, containing different amounts of water of the same temperature, are placed over identical gas burner flames for the same length of time. At the end of that time, the smaller amount of water will have reached a higher temperature. Equal amounts of heat have been supplied, but the increase in temperatures is not equal. As another example, suppose that the water in both pans is at the same temperature, say 80° F, and both are to be heated to the boiling point. It is obvious that more heat must be supplied to the larger amount of water. The temperature rise is the same for both pans, but the quantities of heat necessary are different.

Mechanical Equivalent

Mechanical energy is usually expressed in ergs, joules, or foot-pounds. Energy in the form of heat is expressed in calories or in Btu's. In a precise experiment in which electric energy is converted into heat in a resistance wire immersed in water, the results show that 4.186 joules equals 1 gram-calorie, or that 778 foot-pounds equals 1 Btu. The following equation is used when converting from the English system to the metric system·

$$1 \text{ Btu} = 252 \text{ calories}$$

Specific Heat

One important way in which substances differ from one another is that they require different quantities of heat to produce the same temperature change in a given mass of substance. The specific heat capacity of a substance is the quantity of heat needed, per unit mass, to increase the temperature 1°C. The specific heat of a substance is the ratio of its specific heat capacity to the specific heat capacity of water. Specific heat is expressed as a number which, because it is a ratio, has no units and applies to both the English and the metric systems.

Water has a high specific heat capacity. Large bodies of water on the earth keep the air and the surface of the earth at a fairly constant temperature. A great quantity of heat is required to change the temperature of a large lake or river. Therefore, when the temperature of the air falls below that of such bodies of water, they give off large quantities of heat to the air. This process keeps the atmospheric temperature at the surface of the earth from changing very rapidly.

TEMPERATURE

If an object is hot to the touch, it is said to have a "high" temperature; if it is cold to the touch, it has a "low" temperature. In other words, temperature is used as a measure of the hotness or coldness of an object being described. However, hotness and coldness are only relative. For example, on a cold day, metals seem colder to the touch than nonmetals because they conduct heat away from the body more rapidly. Also, upon leaving a warm room the outside air seems cooler than it really is. Going from the outside cold into a warm room, the room seems warmer than it really is. In other words, the temperature a person feels depends upon the state of his body.

Thermometers

The measurement of temperature is known as THERMOMETRY. Many modern thermometers use liquids in sealed containers. Water was the first liquid used, but because it freezes at 0° C it could not measure temperatures below that point. After much experimentation, scientists decided that the best liquids to use in the construction of thermometers are alcohol and mercury because of the low freezing points of these liquids.

LIQUID THERMOMETERS.–The construction of the common laboratory thermometer gives some idea as to the meaning of a change of 1° in temperature. A bulb is blown at one end of a piece of glass tubing of small bore. The tube and bulb are then filled with the liquid to be used. The temperature of both the liquid and the tube during this process are kept at a point higher than the thermometer will reach in normal usage. The glass tube is then sealed and the thermometer is allowed to cool. During the cooling process, the liquid falls away from the top of the tube and creates a vacuum within the thermometer.

For marking, the thermometer is placed in melting ice. The height of the liquid column is marked as the 0°C. point. Next, the thermometer is placed in steam at a pressure of 76 centimeters of mercury and a mark is made at that point to which the liquid inside rises. That is the boiling point or the 100° C, mark. The space between these two marks is then divided into 100 equal parts. These spacings are known as DEGREES. It is this type of thermometer that is used almost exclusively in laboratory work and in testing electrical equipment. It is known as the CENTIGRADE thermometer.

NOTE: Centigrade scale or thermometer may be referred to as Celsius after the inventor.

In English-speaking countries, the FAHRENHEIT thermometer is commonly used for other than physical or chemical laboratory purposes. The freezing point is marked 32° and the boiling point is marked 212°. The space between these marks is divided into 180 equal parts. These divisions are degrees Fahrenheit, named after the scientist who made the first thermometer of this type. In the U.S., weather reports and room temperatures are given in degrees Fahrenheit.

TEMPERATURE CONVERSION.–There are two systems of temperature measurement; it is frequently necessary to convert from one to the other. The range on the centigrade thermometer from the freezing point to the boiling point is 100° C, and the same range on the Fahrenheit thermometer is 180° F. Thus, over the same temperature range, the liquid moves 180 divisions on the Fahrenheit scale for every 100 divisions on the centigrade scale. A change of 5 on the centigrade scale, therefore, is equal to a change of 9° on the Fahrenheit scale. (The ratio 100/180 reduces to 5/9.) Because zero on the centigrade scale corresponds to 32° on the Fahrenheit scale, a difference in reference points exists between the two scales. (See fig. 5-13.)

To convert from the Fahrenheit scale to the centigrade scale, subtract the 32° difference and multiply the result by 5/9. As an example, convert 68° Fahrenheit to centigrade–

$$\frac{5}{9}(68 - 32)$$

$$\frac{5}{9} \times 36 = 20^\circ \text{ C}$$

To convert centigrade to Fahrenheit, the reverse procedure is necessary. First multiply the reading on the centigrade thermometer by 9/5 and then add 32 to the result–

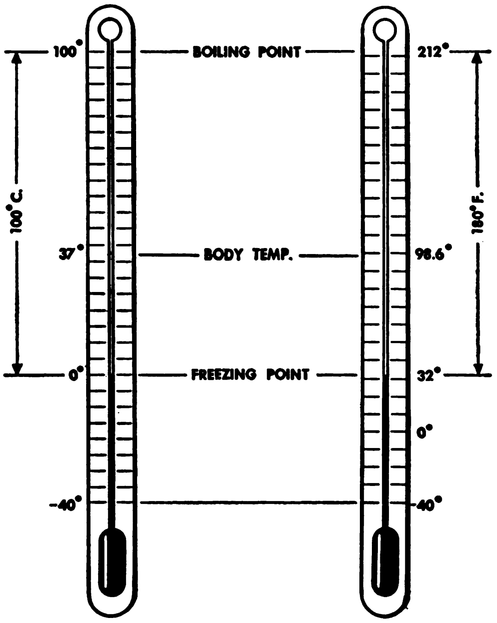


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Figure 5-13.–Fahrenheit and centigrade thermometers.

$$\frac{9}{5}(20) + 32$$

$$36 + 32 = 68^\circ \text{ F}$$

One way to remember when to use 9/5 and when to use 5/9 is to keep in mind that the Fahrenheit scale has more divisions than the centigrade scale. In going from centigrade to Fahrenheit, multiply by the ratio that is larger; in going from Fahrenheit to centigrade, use the smaller ratio.

Another method of temperature conversion which uses these same ratios is based on the fact that the Fahrenheit and centigrade scales both register the same temperature at -40°; that is, -40°F equals -40°C. This method of conversion, sometimes called the "40 rule," proceeds as follows:

1. Add 40 to the temperature which is to be converted. Do this whether the given temperature is Fahrenheit or centigrade.
2. Multiply by 9/5 when changing centigrade to Fahrenheit; by 5/9 when changing Fahrenheit to centigrade.
3. Subtract 40 from the result of step 2. This is the answer.

As an example to show how the 40 rule is used, convert 100° C to the equivalent Fahrenheit temperature:

$$100 + 40 = 140$$

$$140 \times 9/5 = 252$$

$$252 - 40 = 212$$

Therefore, 100° C = 212° F. Remember that the multiplying ratio for converting F to C is 5/9, rather than 9/5. Also remember to always ADD 40 first, then multiply, then SUBSTRACT 40, regardless of the direction of the conversion.

It is important that all technicians be able to read thermometers and to convert from one scale to the other. In some types of electronic equipment, thermometers are provided as a check on operating temperatures. Thermometers are also used to check the temperature of a charging battery.

SOLID THERMOMETERS.–Because the range of all liquid thermometers is extremely limited, other methods of thermometry are necessary. Most liquids freeze at temperatures between 0° and -200° centigrade. At the upper end of the temperature range where high heat levels are encountered, the use of liquid thermometers is limited by the high vapor pressures of those liquids. Among the most widely used types of thermometers other than the standard liquid thermometers are the resistance thermometer, and the thermocouple.

The RESISTANCE THERMOMETER makes use of the fact that the resistance of metals changes as the temperature changes. (See chapter 6 of Basic Electricity, NavPers 10086-B.) This type thermometer is usually constructed of platinum wire wound on a mica form and enclosed in a thin-walled silver tube. It is extremely accurate from the lowest temperature to the melting point of the unit.

The THERMOCOUPLE shown in figure 5-14 is essentially an electric circuit. Its operation is based on the principle that when two unlike metals are joined and the junction is at a different temperature than the remainder of the circuit, an electromotive force is produced. This electromotive force can be measured with great accuracy by a galvanometer. Thermocouples can be located whereever measurement of the temperature is important and wires run to a galvanometer located at any convenient point. By means of a rotary selector switch, one galvanometer can read the temperatures at any of a number of widely separated points.

Thermal Expansion

Nearly all substances expand or increase in size when their temperature increases. Railroad tracks are laid with small gaps between the sections to prevent buckling when the temperature increases in summer. Concrete pavement has strips of soft material inserted at intervals to prevent buckling when the sun heats the roadway. A steel building or bridge is put together with red-hot rivets so that when the rivets cool they will shrink and the separate pieces will be pulled together very tightly.

As a substance is expanded by heat, the weight per unit volume decreases. This is because the weight of the substance remains the same while the volume is increased by the application of heat. Thus the density decreases with an increase in temperature.

Experiments show that for a given change in temperature, the change in length or volume is different for each substance. For example, a given change in temperature causes a piece of copper to expand nearly twice as much as a piece of glass of the same size and shape. For this reason, the lead wires into an electronic tube cannot be made of copper but must be made of a metal that expands at the same rate as glass. If the metal does not expand at the same rate as the glass, the vacuum in the tube is broken by air leaking past the wires in the glass stem. The metal usually used for this purpose is an alloy called "Covar."

The amount that a unit length of any substance expands for a 1° rise in temperature is known as the coefficient of linear expansion for that substance.

COEFFICIENTS OF EXPANSION.–To estimate the expansion of any object, such as a steel rail, it is necessary to know three things about it–its length, the rise in temperature to which it is subjected, and its rate or coefficient of expansion. The amount of expansion is expressed by the following equation:

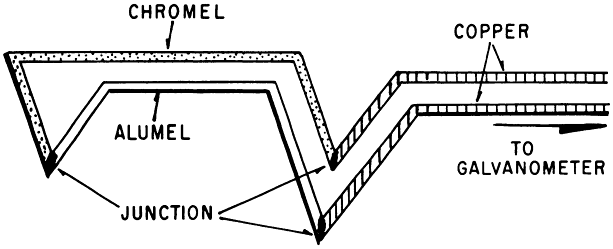
expansion = coefficient x length

x rise in temperature

or

$$e = kl(t_2 - t_1)$$

In this equation, the letter k represents the coefficient of expansion for the particular substance. In some instances, the Greek letter α is used to indicate the coefficient of linear expansion.



AT.33

Figure 5-14.–Thermocouple.

PROBLEM: If a steel rod measures exactly 9 feet at 21° C, what is its length at 55° C? (The coefficient of linear expansion for steel is 11×10^{-6}.) If the equation $e = kl\ (t_2 - t_1)$ is used, then

$$e = (11 \times 10^{-6}) \times 9 \times (55 - 21)$$

$$e = 0.000011 \times 9 \times 34$$

$$e = 0.003366$$

This amount, when added to the original length of the rod, makes the rod 9.003366 feet long. (Since the temperature has increased, the rod is longer by the amount of e. If the temperature had been lowered, the rod would have become shorter by a corresponding amount.)

The increase in the length of the rod is relatively small; but if the rod were placed where it could not expand freely, there would be a tremendous force exerted due to thermal expansion. Thus, thermal expansion must be taken into consideration when designing ships, buildings, and all forms of machinery.

Table 5-2 is a list of the coefficients of linear expansion of some substances.

Table 5-2.–Expansion coefficients.

Substance	Coefficient of linear expansion
Aluminum	24×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Glass	4 to 9×10^{-6}
Covar	4 to 9×10^{-6}
Steel	11×10^{-6}
Quartz	0.4×10^{-6}
Zinc	26×10^{-6}

A practical application for the differences in the coefficients of linear expansion is the thermostat. This instrument comprises two strips of dissimilar metal fastened together. When the temperature changes, a bending takes place due to the unequal expansion of the metals (fig. 5-15). Thermostats are used in overload relays for motors, in temperature sensitive switches, and in electric ovens. (See fig. 5-16.)

The coefficient of surface or area expansion is approximately twice the coefficient of linear expansion. The coefficient of volume expansion is approximately three times the coefficient of linear expansion. It is interesting to note that in a plate containing a hole, the area of the holes expands at the same rate as the surrounding material. In the case of a volume enclosed by a thin solid wall, the volume expands at the same rate as would a solid body of the material of which the walls are made.

CHANGE OF STATE

A thermometer placed in melting snow behaves in a strange manner. The temperature of the snow rises slowly until it reaches 0°C. Provided that the mixture is stirred constantly, it remains at that point until all the snow has changed to water; when all the snow has melted, the temperature again begins to rise. A definite amount of heat is required to change the snow to water at the same temperature. This heat is required to change the water from crystal form to liquid form.

Heat of Fusion

Eighty gram-calories of heat are required to change 1 gram of ice at 0°C to water at

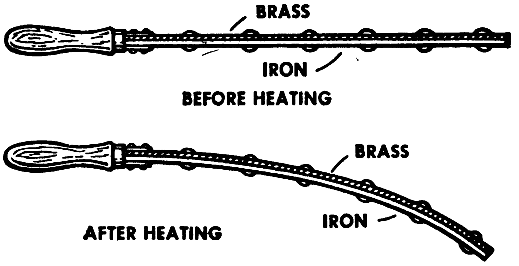


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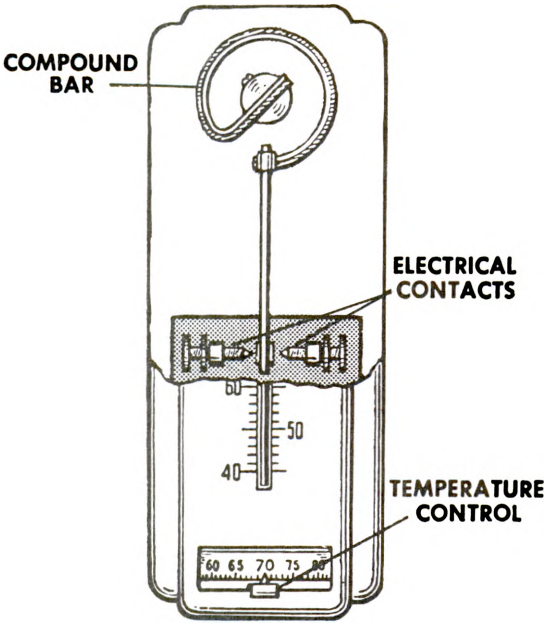
Figure 5-15.—Compound bar.



AT. 35

Figure 5-16.–Thermostat.

0° C. In English units, the heat required to change 1 pound of ice at 32° F to water at 32° F is 144 Btu's. These values are called the HEAT OF FUSION of water. The heat used while the ice is melting represents the work done to produce the change of state. Since 80 calories are required to change a gram of ice to water at 0° C, when a gram of water is frozen it gives up 80 calories.

Many substances behave very much like water. At a given pressure, they have a definite heat of fusion and an exact melting point. There are many materials, however, which do not change from a liquid to a solid state at one temperature. Molasses, for example, gets thicker and thicker as the temperature decreases; but there is no exact temperature at which the change of state occurs. Wax, celluloid, clay, and glass are other substances which do not change from a liquid to a solid state at any particular temperature. In fact, measurements of the glass thickness at the bottom of windows in ancient cathedrals tend to indicate that the glass is still flowing at an extremely slow rate. Most types of solder used in electronics maintenance also tend to become mushy before melting.

Heat of Vaporization

Damp clothing dries rapidly under a hot flatiron but not under a cold one. A pool of water evaporates more rapidly in the sun than in the shade. Thus, it may be concluded that heat has something to do with evaporation. The process of changing a liquid to a vapor is similar to that which occurs when a solid melts.

If a given quantity of water is heated until it evaporates–that is, changes to a gas (vapor)–a much greater amount of heat is used than that which is necessary to raise the same amount of water to the boiling point. For example, several hundred calories are required to change 1 gram of water to vapor at a given temperature. It takes 972 Btu's to change 1 pound of water at 212° F to water vapor (steam) at 212° F. The amount of heat necessary for this change is called the HEAT OF VAPORIZATION of water. Over five times as much heat is required to change a given amount of water to vapor than to raise the same amount of water from the freezing to the boiling point.

BOILING.–When water is heated, some vapor forms before the boiling point is reached. The change from water to vapor occurs as follows: As the water molecules take up more and more energy from the heating source, their kinetic energy increases. The motion resulting from the high kinetic energy of the water molecules causes a pressure which is called the vapor pressure. As the velocity of the molecules increases, the vapor pressure increases. At sea level, atmospheric pressure is normally 29.92 inches of mercury. The boiling point of a liquid is that temperature at which the vapor pressure equals the external or atmospheric pressure At normal atmospheric pressure at sea level, the boiling point of water is 100° C or 212° F.

While the water is below the boiling point, a number of molecules acquire enough kinetic energy to break away from the liquid state into a vapor. For this reason some evaporation slowly takes place below the boiling point. At the boiling point or above, large numbers of molecules have enough energy to change from liquid to vapor and the evaporation takes place much more rapidly.

If the molecules of water are changing to water vapor in an open space, the air currents carry them away quickly. In a closed container, they rapidly become crowded and some of them bounce back into the liquid as a result of collisions. When as many molecules are returning to the liquid state as are leaving it, the vapor is said to be saturated. Experiments have shown that saturated vapor in a closed container exerts a pressure and has a given density at every temperature.

LIGHT

The exact nature of light is not fully understood, although men have been studying the subject for many centuries. Some experiments seems to show that light is composed of tiny particles, and some indicate that it is made up of waves.

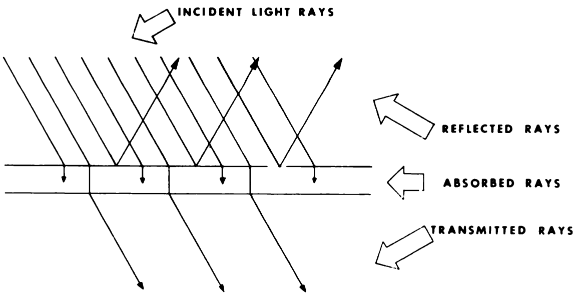
First one theory and then the other attracted the approval and acceptance of the physicists. Today there are scientific phenomena which can be explained only by the wave theory and another large group of occurrences which can be made clear by the particle or corpuscular theory. Physicists, constantly searching for some new discovery which would bring these contradictory theories into agreement, gradually have come to accept a theory concerning light which is a combination of these two views.

According to the view now generally accepted, light is a form of electromagnetic radiation; that is, light and similar forms of radiation are made up of moving electric and magnetic forces.

CHARACTERISTICS

When light waves, which travel in straight lines, encounter any substance, they are transmitted, reflected, or absorbed. (See fig. 5-17.) Those substances which permit clear vision through them, and which transmit almost all the light falling upon them, are said to be transparent. Those substances which allow the passage of part of the light, but appear clouded and impair vision substantially, are called translucent. Those substances which transmit no light are called opaque.

Objects which are not light sources are visible only because they reflect all or part of the light reaching them from some luminous source. If light is neither transmitted nor reflected, it is absorbed or taken up by the medium.



AT.36

Figure 5-17.—Light rays reflected, absorbed, and transmitted.

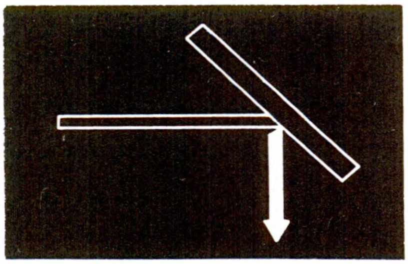
When light strikes a substance, some absorption and reflection always take place. No substance completely transmits, reflects, or absorbs all the light which reaches its surface. Figure 5-17 shows how glass transmits, absorbs, and reflects light.

Reflection

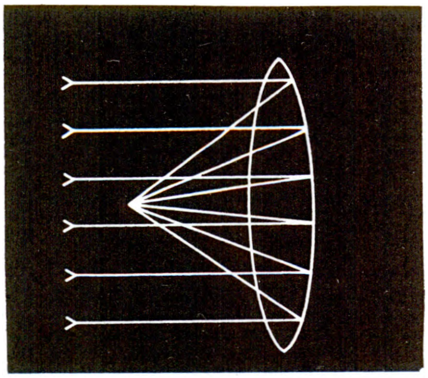
Light waves obey the law of reflection in the same manner as other types of waves. Optical devices incorporated specifically for the purpose of reflecting light are generally classed as mirrors. They may be of a polished opaque surface, or they may be a specially coated glass. In the case of the glass mirror, there is some refraction as well as reflection; however, if the glass is of good quality and not excessively thick, the refraction will cause no trouble. The following discussion is based on the polished surface type mirror.

Several classes of mirrors are illustrated in figure 5-18. All the devices work on the basis of the previously discussed law of reflection, and the applications are only briefly summarized here. Basically, the reflector is used to change the direction of a light beam (A), to focus a beam of light (B), or to intensify the illumination of an area (C).

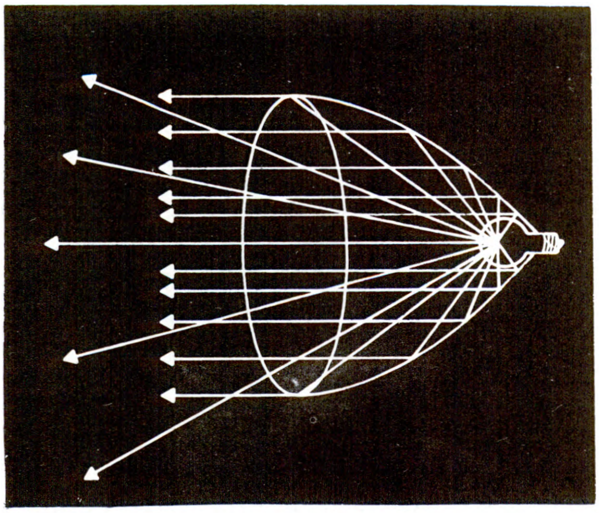
In figure 5-18 (A), the angle of the reflected light may be changed to a greater or lesser degree by merely changing the angle at which the incident light impinges upon the mirror. In figure 5-18 (B), the focusing action of a concave mirror is indicated. The point of focus may be made any convenient distance from the reflector by proper selection of the arc of curvature of the mirror–the sharper the curvature, the shorter



(A) CHANGING DIRECTION



(B) FOCUSING A BEAM



(C) ILLUMINATING AN AREA

Figure 5-18.—Reflectors of light. (A) Changing direction; (B) focusing a beam; (C) illuminating an area. AT.37

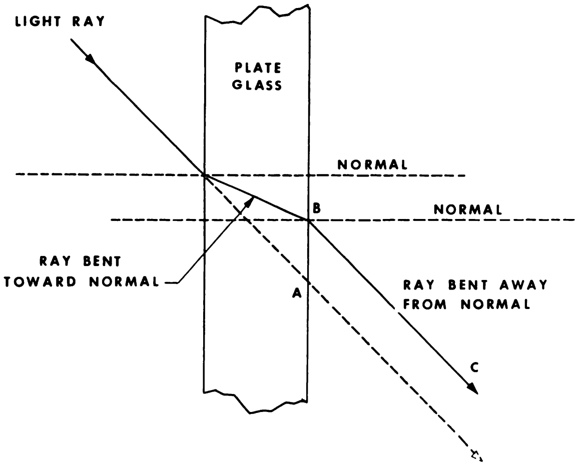
the focal length. In figure 5-18 (C), the principal of intensification of illumination for a specific area is illustrated. The flashlight is an example of this application. In the system shown, note that the light source (bulb) is located approximately at the principal focus point, and that all rays reflected from the surface are parallel. Also note that the reflector alone does not concentrate all the rays—some are transmitted without being reflected and are not included in the principal beam.

Refraction

As light passes through a transparent substance, it travels in a straight line. However, as it passes into or out of that substance, it is refracted in the same manner as other waves which were discussed earlier. Refraction of light waves results from the fact that light travels at slightly different velocity in different transparent mediums. In order to simplify the problem of understanding the action of light reflection and to make it possible to predict the outcome of specific applications, many transparent substances have been tested for refractive effectiveness. The ratio of the speed of light in air to its speed in each transparent substance is called the "index of refraction" for that substance. For example, light travels about one and one-half times as fast in air as it does in glass, so the index of refraction of glass is about 1.5. When using the law of refraction in connection with light, a "denser" medium refers to a medium with a higher index of refraction.

Refraction through a piece of plate glass is shown in figure 5-19. The ray of light strikes the glass plate at an oblique angle. If it were to continue in a straight line, it would emerge from the plate at point A; but in accordance with the law of refraction, it is bent toward the normal and emerges from the glass at point B. Upon entering the air, the ray does not continue on its path but is bent away from the normal and along the path BC in the air. If the two surfaces of the glass are parallel, the ray leaving the glass is parallel to the ray entering the glass. The displacement depends upon the thickness of the glass plate, the angle of entry into it, and the index of refraction for the glass.

All rays striking the glass at any angle other than perpendicular are refracted in the same manner. In the case of a perpendicular ray, no



AT.38

Figure 5-19.–Refraction through a piece of plate glass.

refraction takes place, and the ray continues through the glass and into the air in a straight line.

PRISMS.–When a ray of light passes through a flat sheet of glass, it emerges parallel to the incident ray. This holds true only when the two surfaces of the glass are parallel. When the two surfaces are not parallel, as in a prism, the ray is refracted differently at each surface of the glass and does not emerge parallel to the incident ray.

Figure 5-20 (A) shows that both refractions are in the same direction, and that the ray coming out of the prism is not parallel to the ray going into it. The law of refraction explains what has happened. When the ray entered the prism, it was bent toward the normal; and when it emerged, it was bent away from the normal. Notice that the deviation is the result of the two normals not being parallel.

If two triangular prisms are placed base to base, as in figure 5-20 (B), parallel incident rays passing through them are refracted and caused to intersect. The rays passing through different parts of the prisms, however, do not intersect at the same point. In the case of two prisms there are only four refracting surfaces. The light rays from different points on the same plane are not refracted to a point on the same plane behind the prism. They emerge from the prisms and intersect at different points along an extended common baseline as illustrated by points A, B, and C of figure 5-20 (B).

Parallel incident light rays falling upon two prisms that have been joined apex to apex (fig. 5-20 (C), are spread apart. The upper prism

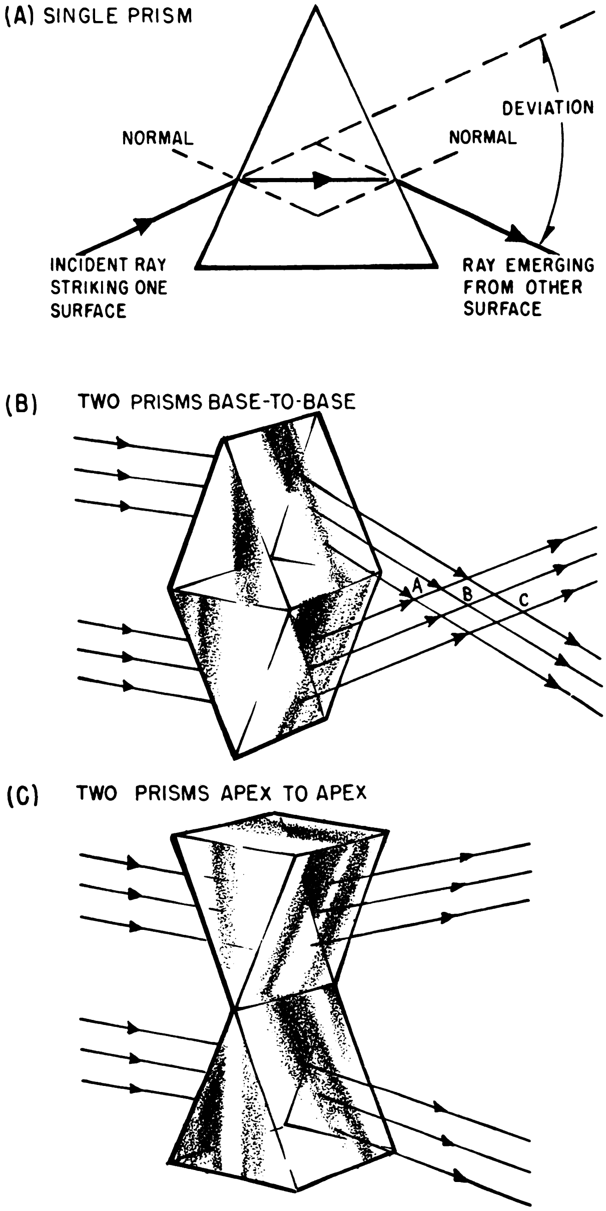

(A) SINGLE PRISM
NORMAL
NORMAL
DEVIATION
INCIDENT RAY STRIKING ONE SURFACE
RAY EMERGING FROM OTHER SURFACE
(B) TWO PRISMS BASE-TO-BASE
A
B
C
(C) TWO PRISMS APEX TO APEX

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Figure 5-20.–Passage of light through a prism. (A) Single prism; (B) two prisms, base to base; (C) two prisms, apex to apex.

refracts light rays toward its base; the lower prism refracts light rays downward toward its base, causing the two sets of rays to diverge.

POSITIVE LENSES.–A positive (convergent) lens acts like two prisms base to base with their surfaces rounded off into a curve. Rays that strike the upper half of the lens bend downward, and rays that strike the lower half bend upward. A good lens causes all wavelengths within each ray to cross at the same point behind the lens as shown in figure 5-21 (A).

When the incident ray of light enters the denser medium (the lens), it bends toward the normal. When it passes through into the less dense medium (the air), it bends away from the normal. Figure 5-21 (B) illustrates the refraction of only one ray of light, but all rays passing through a positive lens are affected in the same way. All incident light rays either parallel or slightly diverging will converge to a point after passing through a positive lens.

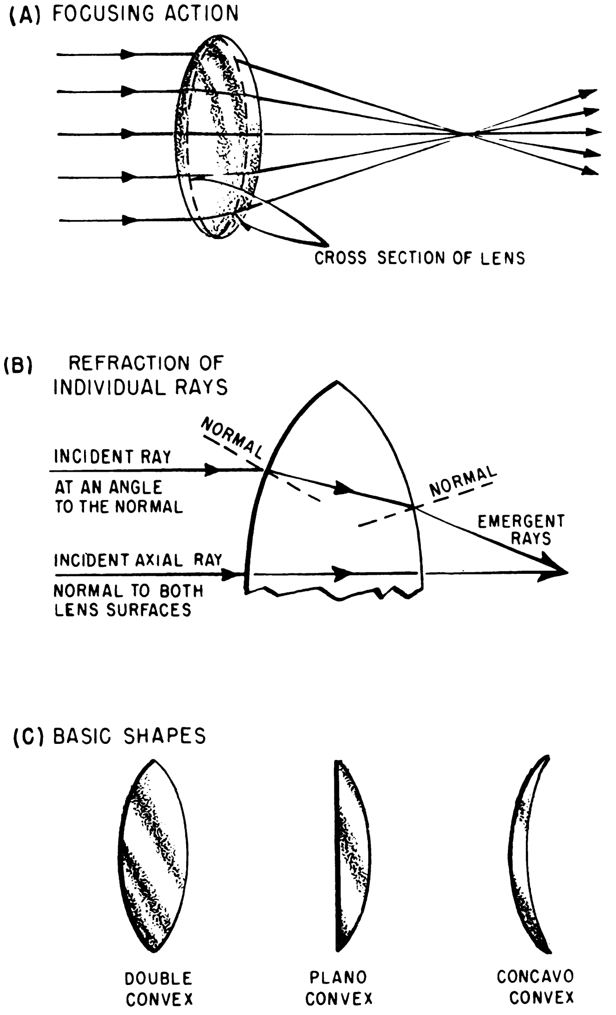

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Figure 5-21.–Positive lenses.

The only ray of light that can pass through a lens without bending is the ray which strikes the first surface of the lens at a right angle, perpendicular or normal to the surface. It passes through that surface without bending and strikes the second surface at the same angle. It leaves the lens without bending. This ray is shown in figure 5-21 (B).

Positive lens and convergent lens are synonymous terms, since either of them may be used to describe the action of a lens which focuses (brings to a point of convergence) all light rays passing through it. All simple positive lenses are easy to identify since they are thicker in the center than at the edges. The three most common types of simple positive lenses are shown in figure 5-21 (C).

NEGATIVE LENSES.–Figure 5-22 illustrates the refraction of light rays by two prisms apex to apex. If the prism surfaces are rounded the result is a negative (divergent) lens. A negative lens is called a divergent lens since it does not focus the rays of light passing through it. Light rays passing through a negative lens diverge or spread apart as shown in figure 5-22 (A).

Figure 5-22 (B) applies the law of refraction to one ray of light passing through a negative lens. Just as in a positive lens, a ray of light passing through the center of a negative lens is not affected by refraction and passes through without bending.

Three simple negative lenses are shown in figure 5-22 (C). They are often referred to as concave lenses and are readily identified by their concave surfaces. The simple negative lenses are thicker at the edges than at the center. They are generally used in conjunction with simple positive lenses where their primary use is to assist in the formation of a sharper image by helping to eliminate or subdue various defects present in an uncorrected simple positive lens.

FREQUENCIES AND COLOR

The electromagnetic waves which produce the sensation of light are all very high in frequency, which means that they have very short

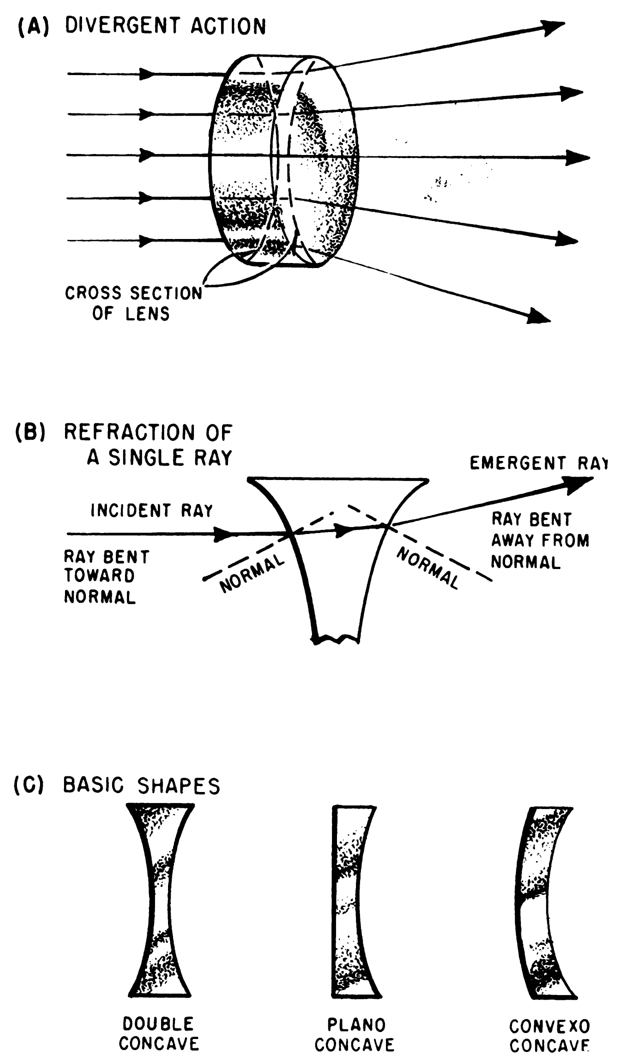

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Figure 5-22.–Negative lenses.

wavelengths. These wavelengths are measured in millimicrons (millionths of millimeters, or 10^{-9} meters). Figure 5-23 indicates that light with a wavelength of 700 millimicrons is red, and that a light with a wavelength of 500 millimicrons is blue-green. This drawing is subject to erroneous interpretation. In actual fact, the color of light is dependent on its frequency, not its wavelength.

When the wavelength of 700 millimicrons is measured in air, it produces a color known as red, but the same wave measured in another medium has a wavelength other than 700 millimicrons. When red light which has been traveling is air enters glass, is loses speed and its wavelength becomes shorter or compressed, but it continues to be red. This illustrates that the color of light is dependent upon frequency and not on wavelength. The color scale in figure 5-23 is based on the wavelengths in air.

All color-component wavelengths of the visible spectrum are present in equal amounts in white light. Variations in composition of the component wavelengths result in other characteristic colors.

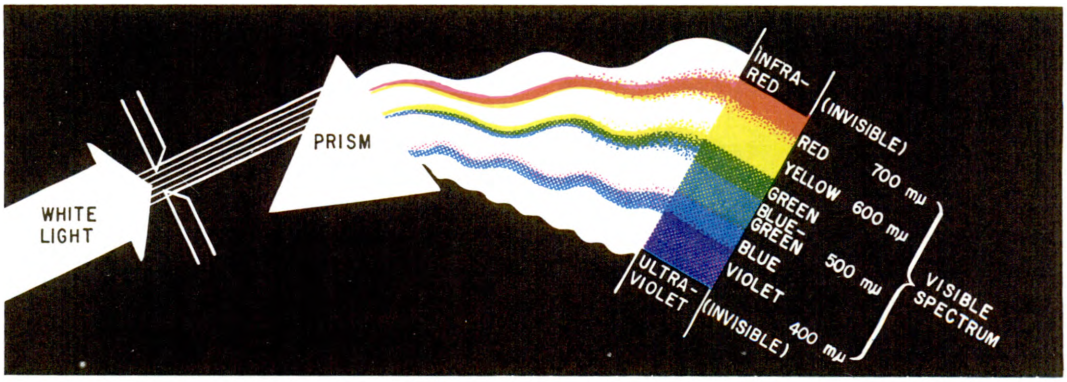
When a beam of white light is passed through a prism, as shown in figure 5-23, it is refracted and dispersed into its component wavelengths. Each of these wavelengths reacts differently on the eye which then sees the various colors that compose the visible spectrum. The visible spectrum is recorded as a mixture of red, orange, yellow, green, blue, indigo, and violet. It can be readily demonstrated that white light results when the PRIMARIES (red, green, and blue) are mixed together in over-lapping beams of light. (NOTE: These are not the primaries used in mixing pigments.) Furthermore, the COMPLEMENTARY or secondary colors (magenta, yellow, and cyan) may be shown with equal ease by mixing any two of the primary colors in overlapping beams of light. Thus, red and green light mixed in equal intensities will make yellow light; green and blue will produce blue-green light which is termed cyan; and blue and red light correctly mixed will render magenta (a purplish red).

It should be noted that a few modern texts vary the treatment of the color scale slightly from the seven spectral colors. This is due partly to developments in the mixing values of pigments (paints). This difference in approach is based on a theory that the retina of the eye is equipped with three varying groups of nerves, sensitive roughly to red, green, and blue-violet light.

SOUND

BASIC CONSIDERATIONS

The term sound as generally used refers to hearing; but when used in physics, the term has to do with a particular type of wave motion and with the generation, propagation, transmission, characteristics, and effects of those waves.



REFRACTION OF LIGHT BY A PRISM. THE LONGEST RAYS ARE INFRARED; THE SHORTEST, ULTRAVIOLET

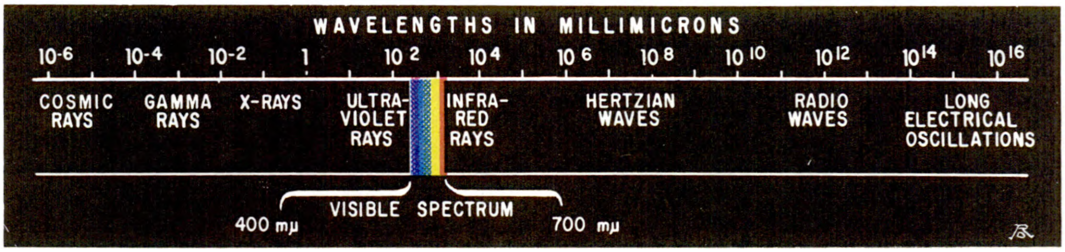


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Figure 5-23.—Electromagnetic wavelengths and the refraction of light.

One example of the generation and propagation of sound waves is the tuning fork discussed earlier in this chapter. Any object which moves rapidly to and fro, or which vibrates rapidly in such a manner as to disturb the surrounding medium, may become a sound source. Sound requires three components—a source, a medium for transmission, and a detector. As widely different as sound sources may be, the waves they produce have certain basic characteristics.

Wave Motion

Sound waves are longitudinal type waves which rely on a physical medium for propagation and transmission. Since the waves are transmitted by the compression and rarefaction of particles of matter in the medium, they cannot be transmitted through a vacuum. Sound waves are similar to waves of other types in that they can be reflected, absorbed, or refracted according to the laws previously discussed; they are also subject to the Doppler effect.

The major differences between the waves of sound and the waves of heat and light are the frequencies, the nature of the wave, and the velocities of wave travel.

Frequencies

Sound waves vary in length; a long wavelength is heard as a low sound, while a short wavelength is heard as a high sound. If the sound is below 15 hertz per second or above 20,000 hertz per second, it normally cannot be heard by the human ear. The frequency range over which sound can be heard is called the audible range, and the sounds heard are known as sonics. Sounds below 15 hertz per second are subsonics; those above 20,000 hertz per second are ultrasonics.

Conduction Media and Velocity of Transmission

In any uniform medium under given physical conditions, sound travels at a definite speed. In some substances, the velocity of sound is higher than in others. Even in the same medium under different conditions of temperature and pressure, the velocity of sound varies. Density and elasticity of a medium are basic physical properties which govern the velocity of sound.

At a given temperature and pressure, all sound waves travel at the same speed in air, regardless of frequency or wavelength. The speed of sound, however, does increase with temperature at the rate of 2.0 feet per second (fps) per degree centigrade. For practical purposes, the speed of sound in air may be considered 1,100 fps. Refer to table 5-3 for speed of sound in various media at different temperatures.

As previously stated, a sound wave is a compressional wave transmitted through an elastic medium. Sound travels faster through water (4,800 fps) than air (1,087 fps) because the elasticity of water is greater than that of air.

For a fixed temperature, the velocity of sound is constant for any medium and is independent of the period, frequency, or amplitude of the disturbance. Thus, the velocity of sound in air at 0° C (32° F) is 1,087 fps and increases by 2 fps for each degree centigrade rise in temperature (1.1 fps for each degree Fahrenheit).

The velocity of sound also varies with a change in altitude. With an increase in altitude, the atmospheric pressure is reduced, and the medium is less dense. Sound waves travel slower in a less dense medium. Therefore, it may be considered that the velocity of sound varies inversely with the altitude.

Table 5-3.—Comparison of velocity of sound in various media.

Medium	Temperature (° F)	Velocity (ft/sec)
Air	32	1,087
Air	68	1,127
Fresh water	32	4,629
Fresh water	68	4,805
Salt water	32	4,800
Salt water	68	4,953
Steel	32	16,410
Steel	68	16,850

Characteristics

Numerous terms are used to convey impressions of sounds, including whistle, scream, rumble, and hum. Most of these are classified as noises in constrast to musical tones. The distinction is based on the regularity of the vibrations, the degree of damping, and the ability of the ear to recognize components having a musical sequence.

The ear can distinguish tones that are different in pitch, intensity, or quality. Each of these characteristics is associated with one of the properties of the vibrating source or of the waves that the source produces. Thus, pitch is determined by the number of vibrations per second, intensity by the amplitude of the wave motion, and quality by the number of overtones (harmonics) which the wave contains. A sound wave can best be described by its frequency rather than by its velocity or wave-length, as both the velocity and the wavelength change when the temperature of the air changes.

PITCH.—The term pitch is used to describe the frequency of a sound. The outstanding recognizable difference between the tones produced by two different keys on a piano is a difference in pitch. The pitch of a tone is proportional to the number of compressions and rarefactions received per second, which in turn is determined by the vibration frequency of the sounding source.

Pitch is usually measured by comparison with a standard. The standard tone may be produced by a tuning fork of known frequency or by a siren whose frequency is computed for a particular speed of rotation. By regulating the speed, the pitch of the siren is made equal to that of the tone being measured. The ear can determine this equality directly if the two sources are sounded alternately, or by the elimination of beats by regulating the speed of the siren if the two sources are sounded together.

INTENSITY.—When a bell rings, the sound waves spread out in all directions and the sound is heard in all directions. When a bell is struck lightly, the vibrations are of small amplitude and the sound is weak. A stronger blow produces vibrations of greater amplitude in the bell, and the sound is louder. It is evident that the amplitude of the air vibrations is greater when the amplitude of the vibrations of the source is increased. Hence the loudness of the sound depends on the amplitude of the vibrations of the sound waves. As the distance from the source increases, the energy in each wave spreads out, and the sound becomes weaker.

The intensity of sound is the energy per unit area per second. In a sound wave of simple harmonic motion, the energy is half kinetic and half potential; half is due to the speed of the particles, and half is due to the compression and rarefaction of the medium. These two energies are 90° out of phase at any instant—that is, when the speed of particle motion is at a maximum, the pressure is normal; and when the pressure is at a maximum or a minimum, the speed of the particles is zero.

The loudness of sound depends upon both intensity and frequency. The intensity of a sound wave in a given medium is proportional to the following 4 quantities:

1. Square of the frequency of vibration.
2. Square of the amplitude.
3. Density of the medium.
4. Velocity of propagation.

At any distance from a point source of sound, the intensity of the wave varies inversely as the square of the distance from the source.

As a sound wave advances, variations in pressure occur at all points in the transmitting medium. The greater the pressure variations, the more intense the sound wave will be. It can be shown that the intensity is proportional to the square of the pressure variation regardless of the frequency. Thus, by measuring pressure changes, the intensities of sounds having different frequencies can be compared directly.

QUALITY.—Most sounds and musical notes are not pure tones. They are mixtures of tones of different frequencies. The tones produced by most sources can be represented by composite waves in which the sound of lowest pitch, the fundamental tone, is accompanied by several harmonics or overtones having frequencies that are 2, 3, 4 or more times that of the fundamental frequency. The quality of a tone depends on the number of overtones present and on their frequencies and intensities relative to the fundamental tone. It is this characteristic of difference in quality that distinguishes tones of like pitch and intensity when sounded on different types of musical instruments (piano, organ, violin, etc.).

ACOUSTICS

Acoustics is the science of sound, including its propagation, transmission, and effect. The performance of an announcing system or sound system when used in a room or enclosed space depends on the acoustical characteristics of the enclosure. Sound originating in an enclosed space is partly reflected and partly absorbed by enclosing surfaces such as the walls, ceiling, and floor of a room. This action introduces echoes and reverberations, which may seriously impair the quality or character of the sound.

Acoustical Disturbances

Light is often thought of first whenever reflection is discussed; however, reflection is equally common in other waves. As an example, echoes are caused by reflection of sound waves.

ECHO.—An ECHO is the repetition of a sound caused by the reflections of sound waves. When a surface of a room is situated so that a reflection from it is outstanding, it appears as a distinct echo, and is heard an appreciable interval later than the direct sound. If the surface is concave, it may have a focusing effect and concentrate the reflected sound energy at one locality. Such a reflection may be several levels higher in intensity than the direct sound, and its arrival at a later time may be particularly disturbing. Some possible remedies for this condition are as follows:

1. Cover the offending surface with absorbing material to reduce the intensity of the reflected sound.
2. Change the contour of the offending surface and thus send the reflected sound in another direction.
3. Locate the loudspeaker in a different position.
4. Vary the amplitude or the pitch of the signal.

REVERBERATION is the persistence of sound due to the multiple reflection of sound waves between several surfaces of an enclosure. It is one of the most common acoustical defects of a large enclosure. Its duration varies directly with the time interval between reflections (the size of the enclosure) and inversely with the absorbing efficiency of the reflecting surfaces. The result is an overlapping of the original sound and its images. If excessive, reverberation causes a general confusion that is detrimental to speech intelligibility. The hangar deck of an aircraft carrier is an example of an extremely reverberant area. The volume is large, and the hard steel interior surfaces offer very little absorption to sound.

If a single loudspeaker is mounted in a large reverberant area, such as a hangar deck, the intelligibility directly in front of the loudspeaker is satisfactory. The intelligibility decreases rapidly with an increase of either the distance from the loudspeaker or the angle between the listener and the loudspeaker's sound axis. In other words, sound from a loudspeaker in a reverberant space is composed of direct sound that reaches the listener directly without any reflection, and indirect sound that has received at least one reflection.

Intelligibility under these conditions is related to the ratio of direct sound to indirect sound. As the listener moves away from the loudspeaker, the ratio of direct sound to indirect sound at the listening position decreases, and the intelligibility decreases correspondingly. Hence, in a highly reverberant space the intelligibility decreases with distance from the loudspeaker.

To prevent the sound from becoming unintelligible in a highly reverberant space, several speakers can be installed about the area rather than just one. The power requirements remain the same; one 25-watt speaker could be replaced by 5 speakers, each consuming 5 watts. This would greatly increase the direct-to-indirect sound ratio.

INTERFERENCE.–Two sound waves moving through the same medium at the same time will advance independently, each producing the same disturbance as if it were alone. The resultant of the two waves can be obtained by adding algebraically the ordinates (instantaneous magnitudes) of the component waves.

Two sound waves of the same frequency, in phase with each other and moving in the same direction are additive. The resultant wave is in phase with, and has an amplitude equal to, the sum of the component waves.

Two sound waves of the same frequency, in phase opposition and moving in the same direction, are subtractive. If the component waves have equal amplitudes, the resultant wave is zero. This addition or subtraction of waves is often called interference.

Two sound waves of slightly different frequency and moving in the same direction produce a beat note. If the two waves originate from two vibrating sources at the same point, and the frequency of one wave is one vibration per second greater than that of the other at a particular instant, the sources will produce additive disturbances at some points and subtractive disturbances at some other points on the relative positions of the waves. These changes will continue to occur as long as the sources are kept vibrating.

The resultant wave has a periodic variation in intensity at a frequency equal to the difference between the original frequencies of the component waves. The difference frequency, referred to as the beat frequency, produces a type of pulsating interference particularly noticeable in sound waves. The effect of beat frequency, called beats, produces alternately loud and soft pulses or throbs. The effect is most pronounced when the component waves have equal amplitudes.

STANDING WAVES.–Two sound waves of equal frequency and amplitude moving in opposite directions through the same medium may produce standing waves. Standing waves are set up by the reaction of the two waves on each other. At certain points they are in phase and at other points they are 180° out of phase. Because their amplitudes are equal, when the two waves act in opposition on a particle, the particle remains motionless. At these points in a standing wave, there is no vibration and the points are called nodes. At the points where the two waves reinforce each other they produce maximum vibrations on a particle. These points are called antinodes. The distance between successive nodes (or antinodes) is a half wavelength.

RESONANCE.–Resonance, or sympathetic vibration, is a common problem encountered in acoustics. It is somewhat more serious than some of the other problems discussed, because the possibility exists for damage to equipment. Reverberation and resonance are frequently confused, but they are distinctly different in nature. Reverberation is a result of the reflection of sound waves and of the interaction between the direct and reflected sound. There is only a single source involved. In resonance, however, the offending object becomes a sound source under certain conditions. This may be explained by the following example:

Assume that the natural frequency of vibration of a steel shaft, which is weighted on one end and held firmly on the other, is 25 vibrations per second. Suppose that with the system at rest, a sound wave produces a force which acts on the shaft with a to-and-fro motion 125 times per second. This force sets the system vibrating at 125 vibrations per second. These vibrations would be of a small amplitude because the rod and weight are trying to vibrate at their natural rate of only 25 vibrations per second. During part of the time the system is resisting the driving force. The motion of the system in this case is called a forced vibration.

If the force is slowed from 125 vibrations per second to its natural frequency of 25 vibrations per second, the amplitude of vibration becomes very large. The amplitude will build up to a point where the driving force is enough to overcome the inertia of the system.

When these conditions exist, the system is said to be in resonance with the driving force, and sound waves are produced by this vibration.

A common example of resonance is found in a crystal oscillator circuit. When an alternating voltage is applied to a crystal that has the same mechanical (resonant) frequency as the applied voltage, it vibrates and only a small applied voltage is needed to sustain vibration. In turn, the crystal generates a relatively large voltage at its resonant frequency.

Measurement of Sound

The range of sound that the human ear can detect varies with the individual. The normal range extends from about 20 to 20,000 vibrations per second. In the faintest audible speech sounds, the intensity at the ear is about 10^{-16} watts/cm^2. At the threshold of feeling, the maximum intensity that the ear records as sound is about 10^{-4} watts/cm^2.

The human ear is a nonlinear unit that functions on a logarithmic basis.

If the ear is tested with tones of any one frequency, the threshold of audibility is reached when the intensity is reduced to a sufficiently low level so that the auditory sensation ceases. On the other hand, the threshold of feeling is reached when the intensity is increased to a sufficiently high level so that the sound produces the sensation of feeling and becomes painful. If this procedure is performed over a wide frequency range, the data can be used to plot two curves, one for the lower limit of audibility and the other for the maximum auditory response (fig. 5-24). Below the lower curve, the sound is too faint to be audible. Above the upper curve, the sensation is one of feeling rather than of hearing; that is, the sensation of sound is masked by that of pain. The area between the two curves shows the pressure ranges for auditory response at various frequencies. Note that the scales of frequency and pressure are logarithmic. An advance of one horizontal space doubles the frequency, and an advance of one vertical space multiples the pressure by ten.

SOUND UNITS.–The loudness of sound is not measured by the same type of scale used to measure length. Units of sound measurement are used that vary logarithmically with the amplitude of the sound variations. These units are the bel and decibel, which refer to the difference between sounds of unequal intensity or sound levels. The decibel, which is one-tenth of a bel, is the minimum change of sound level

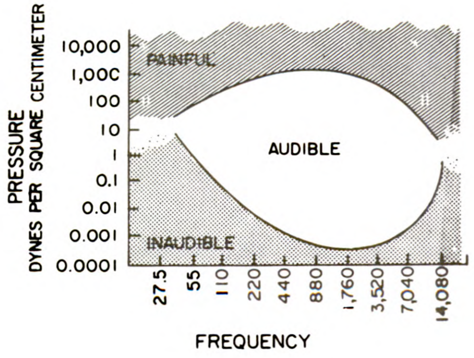

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Figure 5-24.–Field of audibility.

perceptible to the human ear. Hence, the decibel merely describes the ratio of two sound levels. A sound for which the power is 10 times as great as that of another sound level differs in power level by 1 bel, or 10 decibels. For example, 5 decibels may represent almost any volume of sound, depending on the intensity of the reference level or the sound level on which the ratio is based.

In sound system engineering, decibels are used to express the ratio between electrical powers or between acoustical powers. If the amounts of power to be compared are P1 and P2, the ratio in decibels (db) is

$$\text{db} = 10 \times \log \frac{(P2)}{(P1)}$$

(NOTE: When the logarithmic base is not indicated, it is assumed to be 10. The subjects of logarithms and logarithmic relationships are covered in Rate Training Manual, Mathematics, Vol. 2, NavPers 10071-B.)

If P2 is greater than P1, the decibel value is positive and represents a gain in power. If P2 is less than P1, the decibel value is negative and represents loss in power.

INTENSITY LEVEL.–An arbitrary zero reference level is used to accurately describe the loudness of various sounds. This zero reference level is the sound produced by 10^{-16} watts per square centimeter of surface area facing the source. This level approximates the least sound perceptible to the ear and is usually called the threshold of audibility. Thus, the sensation experienced by the ear when subjected to a noise of 40 decibels above the reference level would be 10,000 times as great as when subjected to a sound that is barely perceptible.

ACOUSTICAL PRESSURE.–Typical values of sound levels in decibels and the corresponding intensity levels are summarized in table 5-4. The values in this table are based on an arbitrary zero reference level. Note that for each tenfold increase in power, the intensity of the sound increases 10 decibels. The power intensity doubles for each 3-decibel rise in sound intensity.

Table 5-4.—Values of sound levels.

Sound level (decibels)	Intensity level (watts/cm^2)
0	10^{-16}
60	10^{-10}
80	10^{-8}
100	10^{-6}
110	10^{-5}
120	10^{-4}
130	10^{-3}

POWER RATIO.–The decibel is used to express an electrical power ratio, such as the gain of an amplifier, the output of a microphone, or the power in a circuit compared to an arbitrary reference power level. The value of decibels is often computed from the voltage ratio SQUARED or the current ratio SQUARED. These are proportional to the power ratio for equal values of resistance. If the resistances are not equal, a correction must be made.

To find the number of decibels from the voltage ratio, assuming that the resistances are equal, substitute E^2 for P in the basic equation:

$$\text{db} = 10 \times \log \frac{E2^2}{E1^2} = 10 \times \log \left(\frac{E2}{E1}\right)^2$$

$$\text{db} = 20 \times \log \frac{E2}{E1}$$

To find the number of decibels from the current ratio, assuming that the resistances are equal, substitude I^2 for P in the basic equation:

$$\text{db} = 10 \times \log \left(\frac{I2}{I1}\right)^2$$

$$\text{db} = 20 \times \log \frac{I2}{I1}$$

The power level of an electrical signal is often expressed in decibels above or below an arbitrary power level of 0.001 watt (1 milliwatt) as

$$\text{dbm} = 10 \times \log \left(\frac{P}{0.001}\right)$$

where dbm is the power level above one milliwatt in decibels, and P is the power in watts.

The volume level of an electrical signal comprising speech, music, or other complex tones is measured by a specially calibrated voltmeter called a volume indicator. The volume levels read with this indicator are expressed in "v units" (vu), the number being numerically equal to the number of decibels above or below the reference volume level. Zero vu represents a power of 1 milliwatt dissipated in an arbitrary load resistance of 600 ohms (corresponds to a voltage of 0.7746 volt). Thus, when the vu meter is connected to a 600-ohm load, vu readings in decibels can be used as a direct measure of power above or below 1 milliwatt. For any other value of resistance the following correction must be added to the vu reading to obtain the correct vu value:

$$\text{vu} = \text{vu reading} \ +10 \times \log \frac{600}{R}$$

where vu is the actual volume level, and R is the actual load, or resistance, across which the vu measurement is made. If the volume levels are indicated in units other than vu, the meter calibration, or reference level, must be stated with the decibel value.

CHAPTER 6

ELECTRONIC POWER AND COOLING SYSTEMS

In order to operate and maintain the complex electronic installations of modern naval aircraft, the technician must be familiar with the electric power system of the particular aircraft with which he is associated. Since the electronic installations of aircraft vary widely according to the size and application of the aircraft, the electric power requirements and the electric system components of aircraft also vary. Therefore, the technician must also have a basic understanding of the component parts of the electric system—the power generation equipment, the conversion units, the power control, regulation, and protection components, and the general distribution systems—of typical aircraft.

Today's technician must also have an understanding of the capabilities and limitations of the auxiliary power sources provided for use in ground servicing and maintenance of aircraft. He must be able to operate these units, and must be familiar with the proper procedures for connecting and disconnecting the auxiliary power units to the aircraft. He must know the proper procedures for servicing the auxiliary units, and must observe and enforce all safety precautions and regulations concerning these operations.

The technician must also know the requirements for cooling the various electronic equipment while on the ground. He must be familiar with the sources of auxiliary air and cooling. He must know the operating procedures, as well as the capabilities and limitations of the various cooling units.

This chapter is devoted to a discussion of these topics. In most sections, the topics are discussed in general; in a few instances details are presented as they pertain to specific topics or items of equipment. Coverage of equipments is limited to those expected to be in common usage during the life of this manual.

TYPICAL AIRCRAFT SYSTEMS

The electric power system of an aircraft consists of the power source and its associated controls, the generation system and its associated control and regulation systems, the conversion units, the feeder and distribution system and its component parts, and the various protective devices used throughout the installation.

Most older types of aircraft used engine-driven generators to produce d-c power at a nominal 27.7 volts. Inverters and dynamotors were used as conversion units to produce the voltages required for operation of the individual equipment. With the comparatively simple installations then in use, this arrangement was satisfactory; however, as the installations became more complex, weight problems arose. The increased weight (which resulted from the addition of more and more inverters and dynamotors) soon became prohibitive. A new approach to the problem was required.

As part of the overall effort to standardize aircraft and electronic installations, the supply and distribution of power offered a logical starting point. The first step was to standardize the supply voltages and power frequencies, and to use generators which would provide the required power. Later in the standardization program, the generation of d-c power was discontinued, and the primary power became exclusively a.c.; the d-c requirement was supplied through transformer-rectifiers. This reduced the number of voltages generated, reduced the number of rotary devices, and allowed the use of smaller conductors in the distribution system. The result was a drastic decrease in the total weight of a given installation, which in turn permitted a more complex installation for a given weight allowance.

Even a partial listing of the considerations involved in any discussion of aircraft electric systems must include the following items in order to be of any real value:

1. A "main generating source" refers to all generator units driven by a specified engine; thus a single-engine aircraft can have only one main source.
2. Multiengine aircraft may have a main generating subsystem for each engine. This is the usual practice, but it is not universally followed.
3. In multigenerator systems, provisions may or may not be made for parallel operation of generators producing similar power. If parallel operation is provided, provisions must also be made for individual operation of the subsystems in the event of a failure within the paralleling system.
4. Adequate frequency regulation and stability in a-c generation systems required some method of speed control of the generator's rotor drive mechanism.
5. Provisions must be made to insure that adequate power is available in each mode of operation. In the event of failure of the aircraft engine or its associated generation system, the maximum amount of power which can be produced is decreased. In the case of single-engine aircraft this automatically constitutes an emergency situation.
6. The failure of a single generator or engine in a multiple installation does not constitute the same degree of emergency as the same failure in a single-engine installation. Although some restrictions are placed on operational capabilities, some degree of safety may usually be maintained with the remaining engines and generators.
7. Provisions should be made to enable use of external power sources for starting the engines while on the ground and for ground operation without using the aircraft engines. The aircraft electric system must include provisions to prevent applying both internally-generated power and externally-furnished power to the system at the same time.

AIRCRAFT ELECTRIC SYSTEMS

The electric system of each model aircraft has features which are peculiar to it alone, while other features are common to most models. This section is devoted primarily to a general discussion of the electrical system of a typical aircraft, with some subsequent details concerning the electric systems of actual aircraft.

Source of Power

The basic source of power for the electrical system is the aircraft engine. An a-c generator requires a constant rotational speed in order to produce a constant frequency output. In most modern aircraft, a constant speed drive (CSD) unit is inserted between the aircraft engine and the a-c generator for this purpose.

The constant speed drive unit acts as a variable-ratio differential transmission system which converts the variable speed of the engine to the constant speed required by the generator. The engine is mechanically coupled to the input of the CSD unit; the output of the CSD is mechanically coupled to the rotor of the generator. Internal coupling between the input and output sections of the CSD unit is usually hydraulic, using the engine's oil supply as the transmission coupling medium. Output speed of rotation is controlled by means of mechanical governors and/or electronic speed regulators.

Generation System

The heart of the electric generation system is the constant-speed, wye-connected, a-c generator. This unit normally produces a 3-phase output voltage of about 120/208 volts at 400 Hz which is subsequently regulated to 115/200 volts. The basic theory of a-c generators is discussed in chapter 16 of Basic Electricity, NavPers 10086-B.

An underspeed switch is normally connected to the output shaft of the CSD unit. This is a centrifugally-operated switch and is normally in the open position; it closes only when the output end of the CSD (which is also the generator shaft) reaches a preset speed of rotation. When the switch is open, the electrical system cannot be energized. An overspeed switch is also sometimes used.

STATIC EXCITER.—In most aircraft generators, the rotor receives its excitation from a separate static exciter rather than from a primary rotating exciter (as in the system described in Basic Electricity, NavPers 10086-B). Use of the static exciter eliminates the commutator and its associated problems; coupling from the exciter output to the generator rotor is accomplished through the simpler brush and slipring arrangement.

The heart of the static exciter is the saturable current potential transformer (SCPT). Figure 6-1 shows one phase of the exciter operation. The SCPT is a 3-phase transformer with four separate windings. The current windings carry all of the output current of the generator and, when the load equipment is being used, these windings supply most of the field power requirements. The potential winding is used mainly during initial buildup (when there is no load current flowing).

In series with the potential winding is a linear reactor which shifts the phase of the signal derived from line voltage and reduces it to the correct magnitude. The third winding is the transformer output winding which delivers field power to the generator. The output winding voltage is rectified in a 3-phase full-wave rectifier circuit and fed to the field of the generator (through a brush and slipring assembly).

The last winding is the d-c control winding, which is connected to the output of the voltage regulator and controls the saturation of the transformer core. As more control current flows in the control winding, there is less coupling between the primaries and the secondary or output transformer windings. The control winding (in effect) changes the unit from an iron core to an air core transformer by controlling the saturation level of the magnetic cores.

PARALLEL OPERATION. — Most multi-engine aircraft utilize more than one a-c generator to supply the electrical and electronic loads. The practice of operating multigenerator systems in parallel makes possible the equal distribution of loads between the generators. Parallel operation simplifies the problem of transferring loads when one of the generators is removed from the line and permits a finer frequency control than is provided by the basic constant speed drive governor.

Paralleling circuitry senses both the frequency and the phase relationship between individual generators. If either the frequency

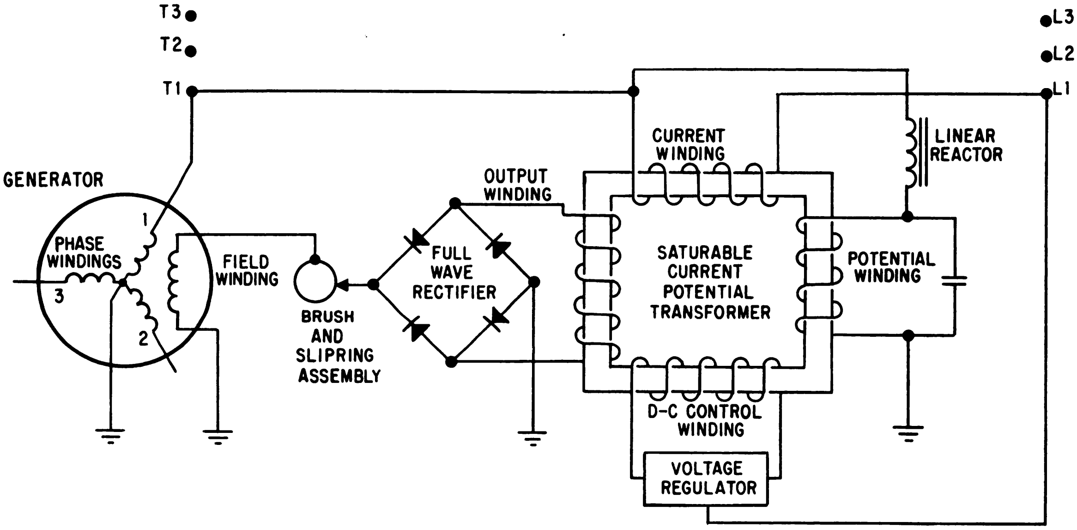

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Figure 6-1.—Static exciter, simplified diagram.

or the phase relationship of the generators is not within permissible limits, parallel operation is not possible. When both these parameters are within tolerance, a paralleling relay operates and supplies power to the coil of a bus tie contactor. Once the bus tie contactor energizes, it is kept closed through an auxiliary set of its own contacts. If the operation of either generator exceeds allowable limits, the bus tie contactor opens and the generators are returned to individual operation.

Division of generator loads involves distributing both the real load (watts) and the reactive load (volt-amperes, reactive). In most parallel systems real loads are equalized by controlling the torque input of each CSD as a function of the difference in watts output. In systems which also equalize the reactive loads, an imbalance activates a reactive biasing circuit. This circuit develops error/correction signals for each generator so as to reestablish a reactive output current balance between the individual generators.

SINGLE-PHASE PMG.—Some main 3-phase a-c generators incorporate a small single-phase permanent magnet generator (PMG) as an integral part of the unit. The permanent magnet rotor is mounted on the main generator shaft, and contains the same number of poles as the main generator; therefore it produces the same output frequency.

The PMG is used to provide the power required for initial buildup of the main generator field; it also supplies power for the controls and regulation system.

D-C GENERATOR.—In most older aircraft all electric power was generated as d.c. In most of the newer aircraft no d.c. is generated; the d-c requirements are met by transforming and rectifying the a.c. In some presently operational aircraft, however, the main power generation system provides both a-c and d-c voltages from a common unit. In other aircraft models, a separate generator is used to provide the d-c power required for operation of the d-c components. This method is not common in airborne applications because of the limited number of prime movers (engines) available.

The basic theory of d-c power generators is presented in chapter 18 of Basic Electricity, NavPers 10086-B.

EMERGENCY GENERATORS.—In the event of failure or shutdown of the aircraft's engines or main generators, the electric system becomes inoperative. The aircraft, however, must have electrical power in order to maintain adequate flight control. All naval aircraft incorporate an auxiliary or emergency generator which operates independently of the aircraft engine.

The most common type of emergency generator is the ram air turbine (RAT). It is normally enclosed within the fuselage, being projected into the airstream when its operation is necessary. Driving power for the rotor is derived from the movement of a turbine through the air; it can be operated only in flight or with blast air when on the ground.

Due to its relatively small size, the emergency generator cannot supply the electric loads required for normal operation of the aircraft. Therefore only those systems and equipments considered essential for the maintenance of flight are operable when the aircraft is dependent on the emergency generator.

Because the rotor of the ram air turbine generator turns at a variable speed (dependent on the speed of the aircraft in flight), frequency stability is not so refined as that of the main generators. A governor is usually incorporated to limit rotational speed; the frequency is thus prevented from becoming too high. No solution has yet been found for maintaining operation of the generator when the aircraft speed drops below a certain point. Therefore, in the event of a power-off landing, all electric power and stability control is lost before the aircraft rolls to a full stop.

System Voltage Regulation

Voltage regulators are incorporated in all electric generation systems. Although similar in basic purpose, the configuration and details of operation vary with each type. Basic theory of voltage regulation and regulator devices is presented in chapters 16 (for a.c) and 18 (for d.c.) of Basic Electricity, NavPers 10086-B. A practical 3-phase a-c static voltage regulator, specifically designed for aircraft usage, is shown in simplified form in figure 6-2 and discussed in the following paragraphs.

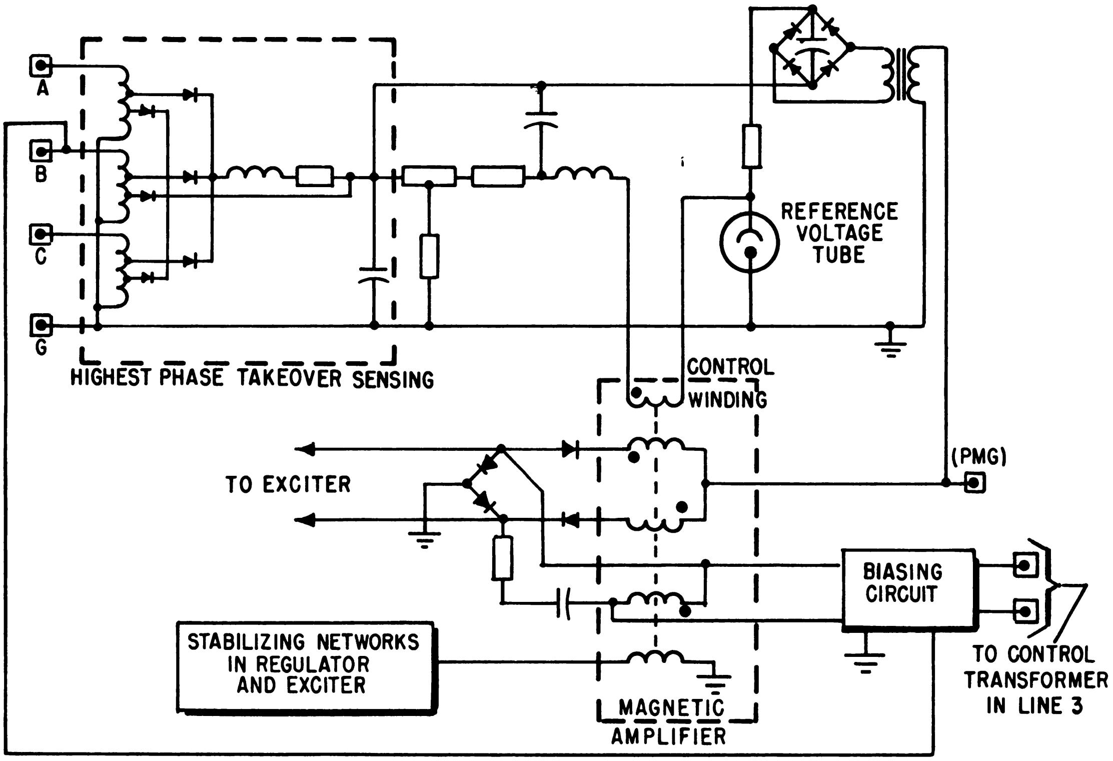
A
B
C
G
HIGHEST PHASE TAKEOVER SENSING
REFERENCE VOLTAGE TUBE
CONTROL WINDING
TO EXCITER
(PMG)
BIASING CIRCUIT
TO CONTROL TRANSFORMER IN LINE 3
STABILIZING NETWORKS IN REGULATOR AND EXCITER
MAGNETIC AMPLIFIER

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Figure 6-2.—Voltage regulator, simplified schematic.

The voltage sensing circuit of the regulator incorporates a highest phase takeover (HPT) circuit developed specifically for aircraft systems. This circuit permits regulation of the average of the 3-phase voltages during normal system operation and during slightly unbalanced conditions of the system. Large unbalanced load conditions result in large unbalanced voltages. The HPT circuit allows regulation of the highest individual phase-to-neutral voltage. The unit thus incorporates the advantages of both the average voltage sensing circuit and the highest phase voltage sensing circuit.

The output of the HPT circuit is compared with an accurate voltage obtained from a cold cathode voltage reference tube. Any difference between the sensed voltage and the voltage reference causes a current to flow in the control winding of a magnetic amplifier. This amplifier is energized by a single-phase a-c voltage, such as that produced by the permanent magnet generator previously discussed. The current in the control winding determines the current output of the PMG to the magnetic amplifier output circuit. The output of the magnetic amplifier supplies the control winding of the saturable current potential transformer.

If the voltage rises at the generator terminals, the output voltage from the sensing circuit increases. This in turn increases the error signal between the sensing circuit and the glow tube reference, and adds to the current in the control winding of the magnetic amplifier. The increased current tends to increase the magnetic amplifier's output current, which then passes through the control winding of the SCPT and makes it behave more like an air core transformer. This reduces the output power. Since the output power of the SCPT is the input power to the generator field, the terminal voltage of the generator is lowered to its required level.

Power Conversion Devices

In most naval aircraft, the main electric power generation system produces 3-phase a-c power at 400 Hz. All aircraft require various levels and quantities of d-c power, and in many instances a-c power of a different frequency is also required. In these cases, various devices are needed to convert the power from the forms generated into the form required for the specific application. A few important conversion devices are discussed briefly in the following paragraphs.

TRANSFORMER-RECTIFIERS.—The most common conversion device for changing a-c to d-c is the transformer-rectifier. The 3-phase, 115-volt a.c. is reduced in a stepdown transformer and then rectified to produce the 28-volt d.c. required for operation of various relays, lights, instruments, mechanical devices, etc. Specific transformer-rectifier units are discussed in the electrical section of the maintenance instruction manual for each model aircraft; the fundamental theory of transformers is discussed in chapter 16, and the metallic rectifier is discussed in chapter 15, of Basic Electricity, NavPers 10086-B.

INVERTERS.—An inverter is a rotating electromechanical device used to convert low voltage d.c. into a.c. It consists essentially of a speed governed d-c motor, an armature and brush assembly, and a permanent magnet inductor type a-c generator, all within a single unit the armature and the permanent magnet rotor are usually mounted on a common shaft. Figure 6-3 and the following paragraphs are based on the E1616-2 inverter used in the P-3 Orion patrol aircraft.

The d-c motor is of the compound-wound type discussed in chapter 19 of Basic Electricity. Motor speed is controlled by a resistor in series with the ground end of the shunt field. The resistor is cut in or shorted out of the circuit by action of a centrifugal switch mounted on the rotating shaft. Electrical connection to the switch is provided by a brush and slipring arrangement. When the inverter is at rest the switch contacts are closed, and the resistor is shorted out as shown in the top section of figure 6-3 (C).

When line voltage is initially applied (fig. 6-3 (B)), full field strength is developed, resulting in large starting torque. Acceleration is rapid. When rotation begins, the contacts of the centrifugal switch tend to be forced open but are restrained by springs. The upper contact of the switch is restrained by a comparatively weak spring; the bottom contact is restrained by a somewhat stronger spring. At some preset speed (usually 5,000 to 7,000 rpm) the upper switch contact is displaced by centrifugal action, opening the switch (middle section of fig. 6-3 (C)). The short is thus removed from the resistor, field current is reduced, and magnetic flux is weakened. These changes combine to result in armature speed acceleration and increase the centrifugal force on the springs.

At approximately 12,000 rpm the lower contact is also displaced by centrifugal action, making contact with the upper contact (whose movement is limited by the preadjusted screw stop). The resistor is once again shorted out (bottom section of fig. 6-3 (C)), the field strength is increased, and motor speed tends to decrease. The speed does not drop noticeably, however, because the make-and-break action of the centrifugal switch is repeated rapidly with any slight change in rotational speed. This feature provides a high degree of speed stability and minimizes the hunting effect.

The generator section features a permanent magnet rotor, mounted on the same shaft as the rotor of the motor. Rotation of the shaft causes an a-c voltage to be induced into the generator's output windings in the stator. The magnitude of the voltage is determined by the strength of the permanent magnet, the number and position of the turns in the windings, and the rotational speed of the magnet. Output frequency is determined by the number of pole pairs of the rotor and the speed of rotation. Since the inverter provides good speed stability, the output voltage and frequency are fairly well regulated. Filtering and additional regulation are included because of possible effects of the load on the line voltage.

The inverter's output frequency and voltage should be checked periodically to assure that they are within prescribed limits. Should adjustment be required, notify the electrical shop since adjustment of inverters is a responsibility of the AE rating.

DYNAMOTORS.—A dynamotor is a rotating electromechanical device used to change (usually,

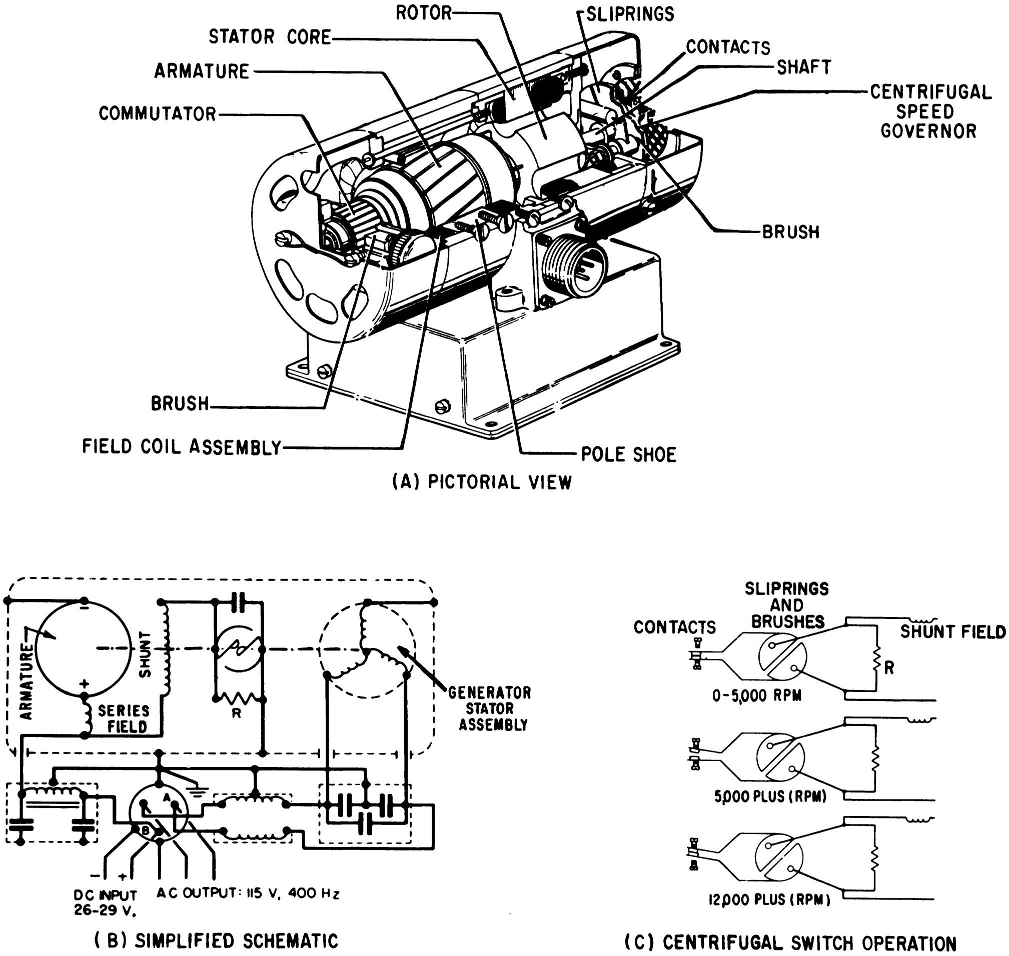

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Figure 6-3.—E1616-2 inverter. (A) Cutaway view; (B) simplified schematic; (C) governor contact operation.

to increase) the level of a d-c voltage. It is essentially a d-c motor and a d-c generator mounted or wound on a common form and shaft, and contained within a single housing. A single stationary field is used to provide the magnetic field for both the motor section and the generator section. The armature consists of two sets of rotor windings wound on a common core mounted on the rotating shaft; the two sets of rotor windings are connected to separate commutators. The motor section serves to produce the driving force; the generator section produces a d-c output whenever the shaft rotates.

Although dynamotors were quite prevalent in older aircraft and electronic systems, they are no longer in common usage.

FREQUENCY CHANGERS.—When a-c voltages of a frequency different from that produced by the main generator are required, suitable motor-generator combinations are used. Main electric power frequency is usually 400 Hz; many aircraft provide a 60-Hz source for test equipment and an 800-Hz source for certain instruments or components.

System Protection

The aircraft electric system incorporates circuits designed to protect the system from damage which could result from malfunction or nonoperation of components in the generation system. Protection requirements and system components vary in different model aircraft, so the circuits are not standardized in configuration. This discussion is based on functional application rather than on operating theory.

OVERVOLTAGE.–In overvoltage protective circuits, a relay deenergizes the system when the line voltage exceeds preset limits. In elaborate system, a "highest phase takeover circuit" and a "reactive biasing circuit" are incorporated to provide added protection. Line voltage is sensed and compared with a reference voltage. If the line voltage is too high, and remains excessive for a preset time interval, the protective circuit assumes control and removes the generator from the line.

UNDERVOLTAGE.–The undervoltage relay removes the generator from the line whenever the system voltage drops below a preset limit; sensed voltage is compared with the same reference as that used in the overvoltage protective circuit. Thus the system is protected whenever the voltage supplied to the line is either above or below the narrow range established by the biasing of the relays.

PMG TRANSFER.–This circuit is used in generation systems in which a permanent magnet generator is used to furnish power for the generator controls. If a malfunction occurs in the PMG (or its leads to the control panel), the source of control power is shifted to one of the phases of the main generator. Shifting of power sources is accomplished without interruption by operation of the permanent magnet generator control transfer relay. Once the system has become deenergized, however, the main generator cannot be built up again using the failed PMG.

DIFFERENCE CURRENT.–This circuit is used in paralleled multigenerator systems where the load is evenly distributed between the generators. As soon as the circuit detects an imbalance in excess of allowable limits, a thermal time delay is initiated. If the unbalanced condition persists, the thermal delay relay opens and locks the bus tie contactor out of the system. The individual generators then operate as isolated systems, each supplying its own loads.

SELECTIVE EXCITATION.–This circuit operates in conjunction with the overvoltage and undervoltage relay circuits in paralleled multigenerator systems. If one generator becomes overexcited for any reason, it normally produces an overvoltage and should trip the overvoltage relay for that particular generator. The function of the overexcitation protection circuit is to insure that the overexcited generator is disabled before the malfunction can trip out the relays in an unfaulted generator. Overexcitation is sensed and a signal is developed and routed to each of the overvoltage relays, decreasing the trip point on the overvoltage relay of the faulty circuit and increasing the trip point of the others. Thus the faulty generator is removed from service, while the others remain in operation.

The underexcitation protection circuit functions in a similar manner, except that it biases the undervoltage relay rather than the overvoltage relay. In both cases, the biasing changes result in tripping the faulty generator. The circuit allows tripping of the other generators only if the removal of the faulty generator fails to correct the overvoltage.

PARALLEL OPEN PHASE.–If an open phase develops in one of the generators of a paralleled multigenerator system, excessively high circulating currents may result. These currents could cause erroneous tripping of the overvoltage relay in an unfaulted generator. A parallel open phase relay senses any open phase, and a signal is routed to the relay. When the relay operates, the faulty generator is removed to lower the circulating currents and prevent tripping of the unfaulted generators.

ANTICYCLING.—Systems which are protected by disabling relays are inherently subject to cycling operation. That is, when the operation of a relay removes a faulty component from the line it also removes the cause of its own initial operation; therefore the relay returns to its normal condition and the faulty component is returned to the circuit. If the faulty condition still exists, it trips the relay again, and starts another cycle. Anticycling protection consists of a lockout relay that operates to lock in an open position through a set of its own contacts. Thus the faulty circuit cannot cycle itself–the system remains inoperative until the tripped generator control switch is turned to the OFF position and then returned to the ON position.

External Power

Essentially all aircraft have provisions for application of electric power from an external source for starting the aircraft engines and/or for ground servicing and maintenance without operating the engines. This power, while not generated within the aircraft, is part of the overall electric system of the aircraft. It must be in all aspects compatible with the power generated within the aircraft. Under no circumstances may the internal and external power be utilized at the same time. This is one of the functions of the distribution system, which is discussed briefly below. (The equipments used to supply power in the external mode of the electric system are discussed briefly in a later portion of this chapter.)

Distribution System

Once the electric power has been generated and some of it transformed, it must be distributed to the various components and equipment where it is to be used. In a simple system, with comparatively few equipments and requiring only a single form of electric power, a simple distribution system could be used. In modern naval aircraft, however, with the complex electrical and electronic installations requiring many forms of power, an extremely complex distribution system is required.

Each model aircraft has different electrical requirements; therefore, each distribution system must differ from all others in accordance with individual requirements. The following discussion is presented to illustrate general principles and considerations, rather than to describe any particular system.

The major area of difference between distribution systems of different model aircraft lies in the switching arrangement used to change electric loads from one source to another in the event of a malfunction.

Long range patrol aircraft normally carry a flight engineer as part of its operating flight crew. The flight engineer is responsible for monitoring the operational status of many different systems within the aircraft. In some aircraft he is responsible for distributing individual electric loads among the various sources so as to provide for essentially balanced loads. He is usually responsible for recycling failed systems when it is assumed that the fault has been corrected. Interceptor and other carrier-based aircraft usually do not have a separate flight engineer. The distribution system for these two systems must be quite different in details, even though they may both incorporate all the same basic requirements and capabilities for load distribution.

P-3 ELECTRIC SYSTEM

This aircraft represents an outstanding example of versatility and flexibility in electric systems. It also illustrates several concepts which will probably find general application in future versions of long range aircraft.

The P-3 "Orion" is a land-based, four-engine, long range patrol type aircraft used primarily for ASW operations. Its electric system includes three main generators, which are driven by engines No. 2, 3, and 4. The No. 1 engine is not used in the generation of electric power. Engines No. 2 and 3 operate at a constant speed regardless of power settings, therefore a separate CSD unit is not required—the frequency regulation requirement is supplied by the engine itself. Under normal conditions of operation the entire electric load is supplied by generators driven by engines Nos. 2 and 3. Engine No. 4 is identical to the others. The generator driven by engine No. 4, however, is driven through a 2-speed gearbox. This feature permits the generator to supply power while the aircraft is on the ground and operating with decreased engine power. During normal operation the No. 4 generator is not feeding the loads, but is in a standby condition ready to assume the load of either generator if necessary.

The main generators are statically excited, statically regulated, and controlled from power produced by a PMG mounted on the generator shaft. Power produced by each generator is 117/202-volt, 3-phase, 400 Hz a.c.; the generators are not paralleled. Each has a capacity well in excess of its normal operating loads. Except under conditions of severe icing, only a slight reduction in total load is required for continued operation with a single generator supplying the entire load. To supply deicing power, however, a more drastic reduction in operating loads is needed.

Each generator is provided with undervoltage, overvoltage, differential current, and frequency protection. In addition, a failure warning light is connected to a "run strip" in the generator rotor which indicates any rotor-to-stator short. For generator No. 4, a "disengage" light is connected to high temperature and low pressure sensors in the two-speed gearbox oil system.

Failure of one generator causes no interruption of power because the standby generator automatically and immediately assumes the load normally supplied by the failed generator. "Generator Off" lights are installed for each generator to advise the flight crew when the unit is not available for operation.

Reverse phase protection of the external power connection prevents the power relay from closing if the phase rotation is incorrect.

Power produced by the generators is supplied to a main load center which houses the exciters, regulators, and control and protection devices for each generator. (See fig. 6-4 (A).) The same load center also contains the power transfer relays, the main power distribution buses, two transformer-rectifiers, and miscellaneous circuit breakers, switches, relays, and minor items of equipment. (A third transformer-rectifier is located in the forward load center.)

The power transfer relays are so connected that any of the generators can supply power to either or both buses. Additional relays and wiring (called the "runaround" circuit) permit bypassing the normal transfer relays and distribution feeders, thus supplying power from anyone of the three generators to the essential a-c bus. The three transformer-rectifiers are so connected that the necessary d-c control power is available for all possible connections of the a-c buses. The buses and the switches and relays controlling their connections are indicated in figure 6-4 (B). Reference to this figure should be made at frequent intervals throughout the remainder of this discussion.

Operation of the system during normal flight conditions is entirely automatic. The crew needs only to monitor the circuit breaker and control panels at the load centers for any indication of malfunction.

Control of the system is also automatic during ground operation, except switching to and from external power. A light is provided in the flight station and at the external power receptacle to indicate when external power is being used.

During engine speed changes, the No. 4 engine speed should be reduced first and the No. 4 generator will temporarily be shut off by the frequency sensing relay while the speed is changing and the gearbox shifts; it will then come back on and be available to pick up the aircraft loads when generators No. 2 and 3 drop out due to underfrequency (as a result of reduced engine speed). The speed of engines No. 2 and 3, on the other hand, should be increased before No. 4 and will automatically take over their respective buses when they reach normal operating speed. Power interruption during speed changes is thus limited to the time (30 milliseconds, approximately) required for a normal bus transfer.

Temporary loss of all generator power requires that a source independent of the engine's generators be made available for starting the aircraft engines. Conditions of flight and the size of the essential flight loads are such that the use of a ram air turbine generator for emergency power has been deemed impractical. A 24-volt, 11-ampere-hour, lead-acid storage battery is provided to supply power for ignition and for flashing the field of the generator. (Engine rotation results from windmilling propellers.) Starting load requirements also include a.c., which is supplied by a battery-driven 100-ampere-hour inverter. The inverter and its loads are connected through a "start essential" bus; switching control is through the start selector switch. The bus switches to the battery if no other source of d-c power is available.

To provide for prolonged loss of generator power, a bypass and load monitoring system has been provided. This system provides for three levels of emergency, as follows:

1. BUS A and BUS B switches, when actuated to the OFF position remove all loads except those classed as essential.
2. Actuating the essential bus switch to the OFF position, in addition to the above, removes all but the minimum necessary flight loads.
3. Lifting the guards and turning all three generator switches to the OFF position removes ALL loads on the aircraft except a turn-and-slip indicator, two cockpit utility lights, emergency warning indicator, and the d-c control supplied by the battery.

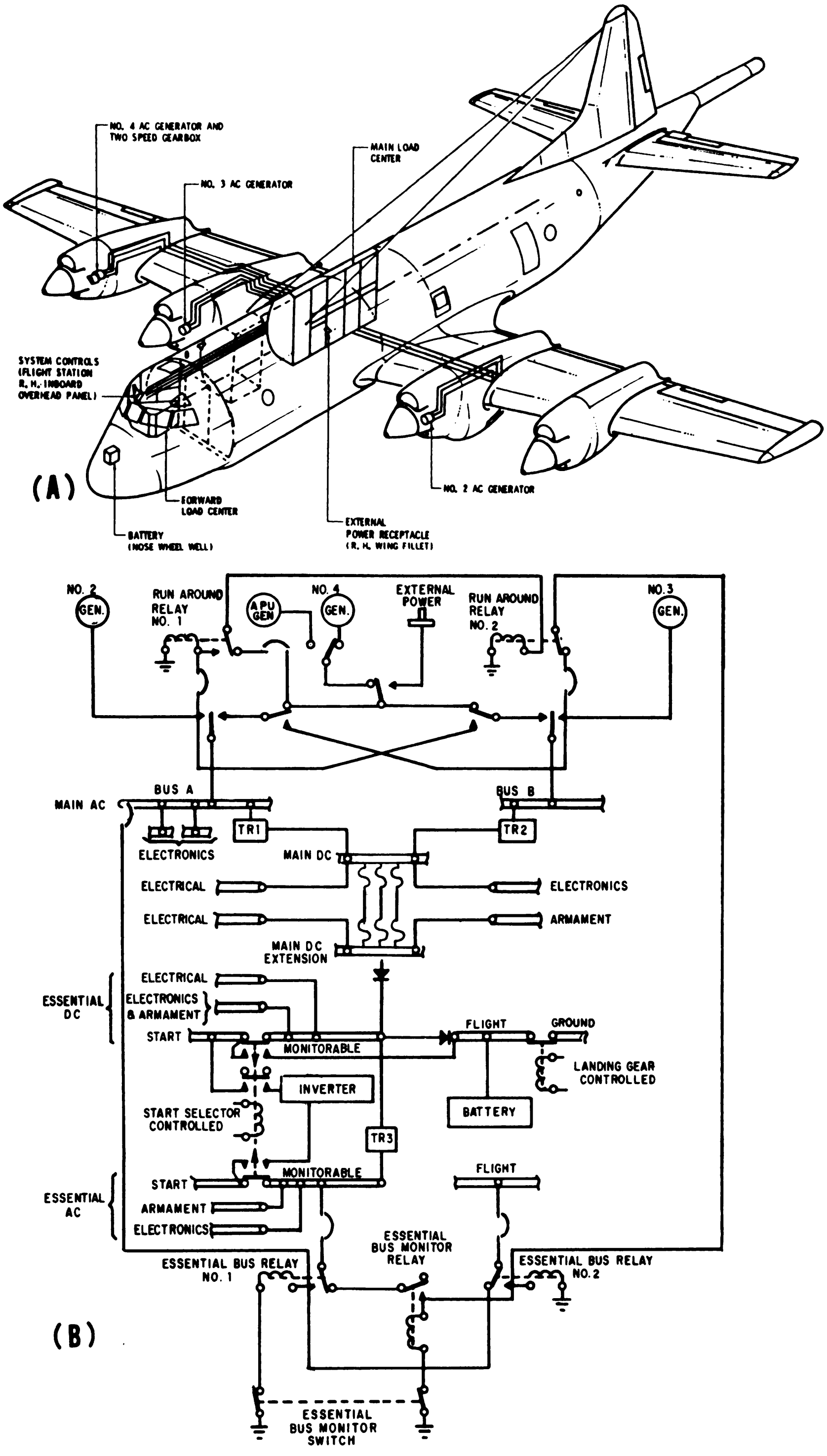

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Figure 6-4.–Electric power distribution in P-3, simplified.

One additional feature of many new models of aircraft, including the P-3, that deserves discussion is the deletion of ammeters and voltmeters from the main control panel. The case for the installation of meters is that an experienced crewmember can gain an appreciable amount of information useful in diagnosing system problems by carefully observing the meters. However, in agreement with the present Naval Air Systems Command design policy, and based on the following reasoning, no voltmeters or ammeters are installed in the P-3 aircraft.

1. The value of meters is basically for maintenance purposes. The voltage is automatically regulated and no adjustment is available to the flight crew.
2. The meters used in conventional control panel installations are not good maintenance instruments.
3. It is not practical to provide voltage and current indications for all points in the system that need to be checked in maintenance.
4. The information obtained by the flight crew from meters may do more harm than good in that it is frequently misinterpreted.

NOTE: An auxiliary power unit (APU) is installed in some P3 aircraft. When the APU is installed, the battery in the nosewheel well is changed from a 24v, 11-ampere-hour type to a 24v, 34-ampere-hour type. On newer aircraft incorporating a starting capability, the 2-speed gearbox is removed from the No. 4 engine.

The APU is gas turbine-driven, providing compressed air for engine starting and air conditioning; it also provides mechanical power to drive a 60-kva Bendix brushless generator whose electrical output is used for ignition during engine starting, ground operation of all aircraft electrical and electronic circuits, and emergency electrical power during flight (possible only on those units that have in-flight starting capability incorporated). APU controls are mounted on the auxiliary power unit control panel which is on the center overhead panel in the flight station.

F-4B ELECTRIC SYSTEM

The F-4B was selected for discussion in this chapter because it offers an example of the continuous process of improving the reliability and simplifying operation of the overall electric system.

The F-4B "Phantom II" is a carrier-based, two-engine, high speed, high altitude, jet interceptor type aircraft. The engines operate at varying speeds according to power settings; therefore a separate CSD unit is needed to provide the generator with a constant speed of rotation. The main power generation system produces a well regulated 115/200-volt, 3-phase, 400-Hz a.c. Part of the a-c power is transformed and rectified to 28-volt d-c power. The system utilizes the static excitation and regulation systems, and incorporates numerous protective features. Main a-c buses are operated in parallel for improved frequency regulation and equalized load distribution, with provision for individual operation in the event of bus tie failure.

New versions of the basic aircraft have incorporated an automatic CSD disconnect system. In older models, the engine was shut down whenever overheating of the generator or CSD unit was indicated. This required operation on single engine and attempted air-starts of the secured engine, with many aborted missions and emergency alerts. With the new unit installed it is no longer necessary to secure the engine, unless the cause of overheating is low oil supply in the engine-CSD-generator system (all three units use a common oil supply for cooling).

Another recent modification, the use of brushless generators, has resulted in increased power output ratings coupled with improvements in the control and regulating components. The modification has decreased total weight, improved reliability, and lowered maintenance requirements.

In early versions of the aircraft, damage to the transformer-rectifiers was frequently caused by the application of external power with reversed phase, improper voltage or frequency, or some other defect. A fuse has been installed in the external power circuit to protect the external transformer-rectifier from damage when any parameter of the external power falls outside tolerances.

A problem common to many aircraft involves the ram air turbine (RAT) emergency generator. In early versions of the Phantom II, the emergency generator supplied hydraulic power in addition to the electric power, for use when both engines were inoperative. This combined requirement limited the RAT to fairly high flying speeds and resulted in the loss of emergency power prior to touchdown in the dead-engine emergency landing. Recent modifications have allowed removal of the hydraulic provisions from the RAT. Improvements to the turbine and its associated generator have permitted the production of adequate emergency electric power at a much lower speed. The newer aircraft can maintain emergency electric power with a speed below that of normal touchdown. Since power decreases rapidly after touchdown, a cutout switch has been installed in the landing gear system. This switch removes the emergency generator from the line upon touchdown and protects the essential bus equipments and components from the effects of low voltage and frequency.

Improvement of the emergency generator system is expected to bring about changes in the essential bus system. The extent and exact nature of these changes is not known at the time of this writing. It is also expected that the parallel operation feature of the main a-c system will be eliminated in an effort to simplify the overall operation of the system.

CIRCUIT PROTECTION AND CONTROL DEVICES

The electric system of an aircraft is protected from damage and failure by fuses, current limiters, and circuit breakers. Control and distribution of power is accomplished by the use of switches and relays. Each of these components is available in many styles and sizes, some of which are ideally suited for use in aircraft while others are limited to use in shop installation. The following section presents a brief discussion of these components.

FUSES

Fuses provide a controlled, intentionally weakened link in an electric circuit. It serves as a safety device in the event of undesired overloads. Fuse sizes are available with ratings of from two milliamperes to several hundred amperes; fuses of most ratings are available for normal, slow-action or fast-action operation.

A fuse is a heat-sensitive, heat-operated device. When operated at rated current it consumes electrical power and dissipates this power in the form of heat. Under normal operating conditions, the dissipated heat is not sufficient to cause the unit to fail; however, when the fuse is operated above the normal current rating, the overload current generates additional heat which melts the fusible element.

Voltage Rating

A fuse can be operated at any circuit voltage, if it is mounted in a sufficiently well insulated holder (as long as the fusible element is able to fail without suffering arc damage). When a fuse fails due to excessive current, the full circuit voltage appears across the open fuse; if inductance is present in the circuit, a surge is generated which may cause a destructive arc to be formed within the fuse. Under these conditions, intense heat and pressure develop and the fuse may literally explode.

Fail-Time Characteristics

The fail-time characteristic of a fuse depends on the percent of rated current and the thermal inertia of the fuse. Overload currents (currents larger than the maximum value for which the fuse is rated) when flowing through a fuse, heat the element beyond normal capacity; after a period of time, the fusible element fails.

Fuse elements with a large thermal inertia increase the length of time before failure. Fuses containing such elements are known as slow-acting, slow-blow, or time-delay fuses. Slow-action fuses are constructed with a compound element; a thermal cutout and a fusible link that melts on short circuits or very high overloads. Small, light fuse elements reduce the thermal inertia and therefore are faster acting. This type of fuse is known as a fast-action fuse and is used principally for the protection of sensitive instruments.

In the selection of a fail-time characteristic, both the steady state and the transient or surge currents are considered. If currents of 200 to 400 percent of normal can be tolerated for periods of 10 seconds, a slow-acting fuse is specified. If the circuit requires immediate protection for any current above normal, a fast-acting fuse is specified. If the current must be limited to 200 percent of the rating for periods less than one second, then a normal, or medium, fail-time characteristic is specified. (See fig. 6-5.)

When possible, a fuse should be operated at about 75 percent of its rated value; this provides a good balance between protection and reliability.

Vibration Resistance

Fuse protection for equipment subject to vibration can be provided by special vibration-resistant construction. This type of fuse has a spring formation, with winglike extensions which bear on the inside wall of the glass body, to decrease vibration of the fuse element. For slow-action fuses, a different construction, consisting of a compound spring and link structure, is used. On moderate overloads, as the compound element reaches the melting point, the spring pulls away from the link; on short circuits, the link fails.

Identification Coding

Fuses and their corresponding fuse holders are numbered according to a standardized system for easy identification. The numbering system is illustrated and explained in figure 6-6; some actual fuses are shown in figure 6-7.

Fuse Holders

The most common class of fuse holders used in Navy equipment is the post type holder shown in figure 6-7. It may be a screw-in or a bayonet type, both of which are securely mounted to the chassis or front panel of the equipment. The purpose of the holder is the same, regardless of type– to hold the fuse securely with good electrical connection and physical stability for protection from mechanical vibration and electrical short circuit.

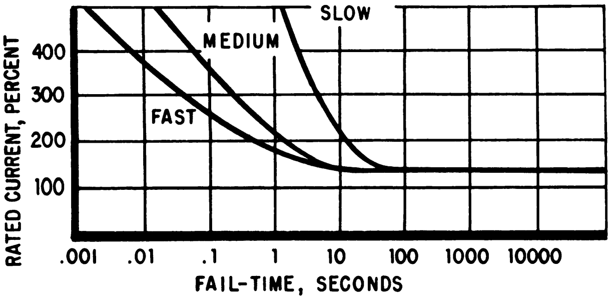

Figure 6-5.–Fail-time characteristics of fuses.

Care should be used to insure that the fuse is of a physical size compatible with the holder. Fuses which are too small allow physical movement and arcing, resulting in a blown fuse or a damaged holder; fuses which are too large may cause cracking or breaking of the holder. Force should never be applied to either the fuse or the holder, since both these are quite delicate.

Post type fuse holders are normally series-connected in the line, with the end connection to the power source and the center connection to the load. When connected in this fashion, the equipment is protected in the event of a broken holder–a short circuit from fuse holder to chassis ground will result in a blown fuse and excessive current will not flow. Reversed connections will not furnish this protection. Connection is normally made by solder connection, although some fuse holders are connected by use of the screw and lug method.

Current Limiters

Devices somewhat similar to fuses, called current limiters, are used in aircraft circuits that carry high currents. (See fig. 6-7.) The current limiter consists of a copper link of carefully predetermined sections. The sections melt when abnormally high currents start to flow. The melting sections have a high arc resistance to keep the circuit current within the capacity of the limiter. If the excessive current is only a temporary surge, the melting ceases and the circuit continues to operate as if no abnormal current had been present. Repeated applications of excessive current, or uninterrupted application for a period of several seconds, melt through the sections and cause the limiter to "blow" in the same manner as a fuse.

CIRCUIT BREAKERS

In modern naval aircraft, circuit breakers have replaced fuses as the main circuit protec-

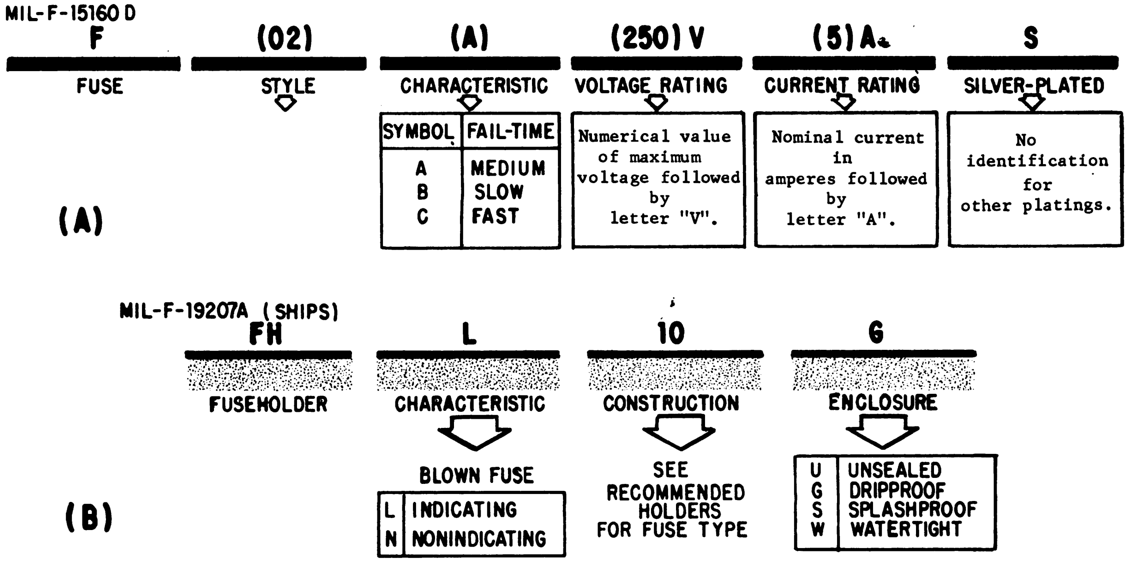

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Figure 6-6.—Identification coding. (A) Fuses; (B) fuse holders.

tion device for most of the wires and cables making up the electrical system. The circuit breaker is designed to open the circuit under short-circuited or overloaded conditions without injury to itself. Thus, it performs the same function as the fuse, but has the advantage that it is capable of being reset and used again. Circuit breakers are rated in amperes and volts.

There are three basic types of circuit breakers (thermal, magnetic, and thermomagnetic), but the following discussion is directed mainly toward the thermal type because it is more generally used. Circuit breakers are divided into three categories—the pushbutton reset type, the toggle type, and the automatic reset type (sometimes called a circuit protector).

The pushbutton reset type consists of a bimetallic, thermally actuated, spring loaded device which closes two electrical contacts when set. This is shown in figure 6-8. An excessive current through the device causes an uneven expansion of the bimetallic mechanism (thermal release) which releases a trigger escapement and permits the spring loading to separate the contact members.

A visual indication of the automatic opening is provided by causing the pushbutton to move to an easily noticed "tripped" position. In this position the button is fully extended and the white ring plus the inner red section of the button is showing. The latest type of pushbutton breakers have a pullout feature which permits manual opening of the circuit, but this type should not ordinarily be used as a switch.

Another type of circuit breaker uses a toggle lever instead of the pushbutton. It operates in the same manner as the previously discussed breaker, with the exception that the tripped condition is indicated by the toggle lever being in the OFF position. This type of circuit breaker has the apparent advantage of also being usable as a switch.

Manual resetting of the circuit breaker may be accomplished by means of the actuator (either pushbutton or toggle lever) whenever the bimetallic thermal element cools sufficiently for the trigger to engage its latching mechanism. In connection with resetting, there are two classifications for circuit breakers; namely, trip-free and non-trip-free.

The non-trip-free circuit breakers can be prevented (by the operator's action) from tripping even though a tripping condition exists. This should be done only in an emergency; since this action is apt to change the calibration, the breaker should be replaced as soon as conditions permit. This type breaker is no longer being installed in new aircraft; however, it is still found on some older models.

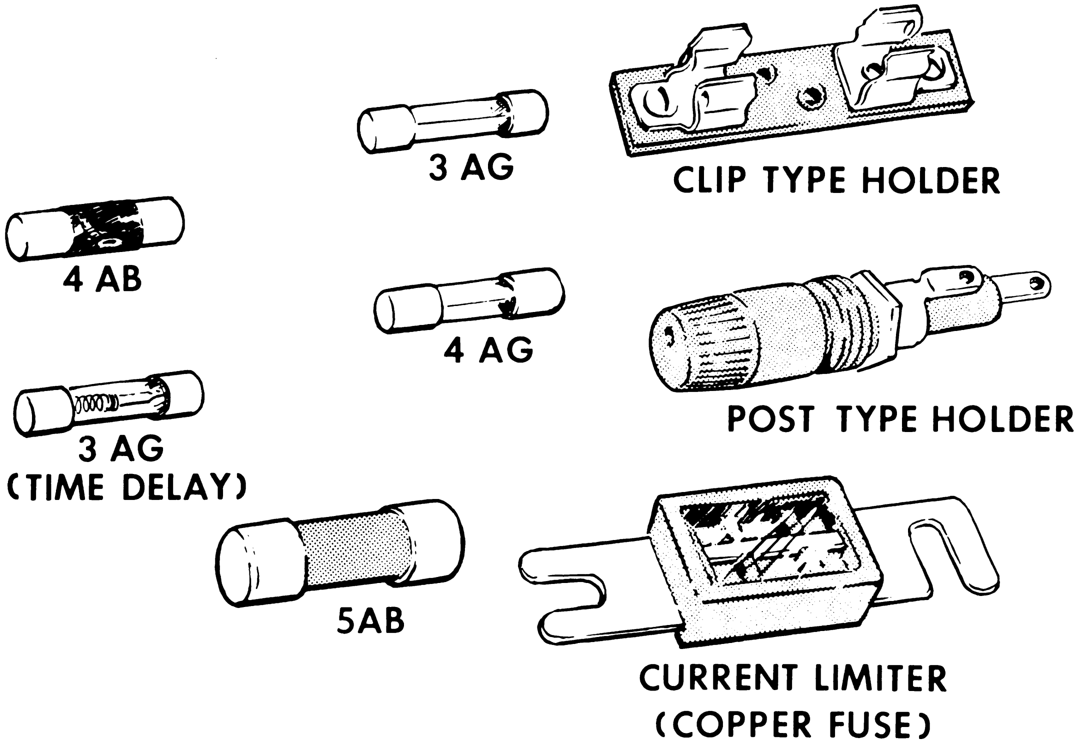

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Figure 6-7.–Aircraft fuses and fuse holders, typical examples.

In the trip-free class, the contacts cannot be kept closed by holding the actuator in the closed (or reset) position as long as an overload condition persists which would otherwise cause normal tripping.

A disk type thermal circuit breaker is shown in figure 6-9. This breaker consists of a conductive bimetallic snap-acting disk which bridges two electrical contacts. When this disk is heated by the excess current through it, it snaps to the reverse position, opening the contacts and breaking the circuit. In circuit breakers having low ratings, a resistance wire is inserted; current through this wire provides the heat necessary to snap the disk. These breakers are reset by pressing a button, restoring the disk to its original position. When circuit breakers of this type are closed, they cannot be reopened manually. They are also nonindicating; that is, the position of the breaker (open or closed) cannot be determined by visual inspection.

The automatic reset type circuit breaker is similar to the bimetallic disk type just described, except that it has no reset pushbutton; it resets itself automatically. After a short time, when the disk has cooled sufficiently, it will bend back and close the circuit, resetting itself. If a constant overload exists, the breaker will intermittently break the circuit.

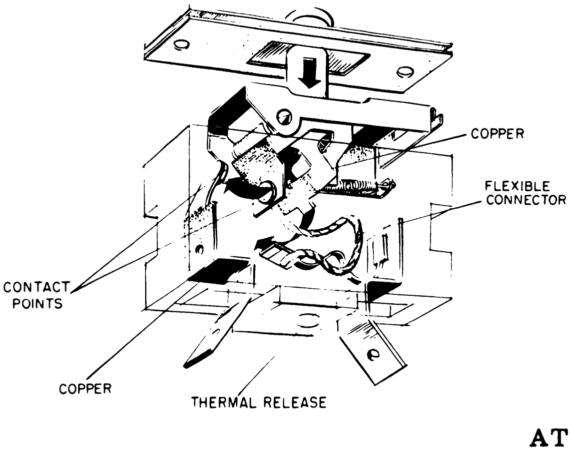

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Figure 6-8.–Thermal circuit breaker.

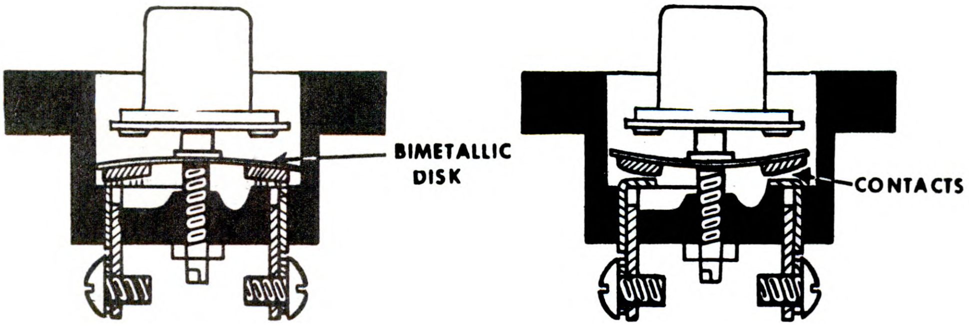

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Figure 6-9.–Thermal circuit breaker (disk type).

Another type of circuit breaker is the switch toggle variety based on magnetic instead of thermal operation. This type can be made to open almost instantly when more than the rated current flows in the circuit. An electromagnet is placed in series with the spring-loaded contacts, and the contacts are mounted so that an armature acts as a latch to hold them closed. When an excess current flows, the armature is pulled toward the electromagnet, releasing the contacts and opening the circuit. To reset the circuit breaker, the contacts are closed manually and the spring-loaded armature returns to its normal position.

SWITCHES

A switch may be described as a device used for making, breaking, or changing connections in an electrical circuit. Switches are rated in amperes and volts; the rating refers to the maximum allowable voltage and current of the circuit in which the switch is to be used. Since it is placed in series, all the circuit current will pass through the switch; because it opens the circuit, the applied voltage will appear across the switch in the open circuit position. Switch contacts should be opened and closed quickly to minimize arcing; therefore, switches normally utilize a snap-action.

Many types and classifications of switches have been developed. A common designation is by the number of poles, throws, and positions. The number of poles indicates the number of terminals at which current can enter the switch. The throw of a switch signifies the number of circuits each blade or contactor can complete through the switch. The number of positions indicates the number of places at which the operating device (toggle, plunger, etc.) will come to rest. Figure 6-10 presents the schematic diagram of some typical switches.

An example of the switch position is a toggle switch which comes to rest at either of two positions, opening the circuit in one position and completing it in another. This is called a two-position switch. A toggle switch which is spring loaded to the OFF position and must be held in the ON position to complete the circuit is called a single-position switch. If the toggle switch will come to rest at any of three positions, it is called a three-position switch.

Another means of classifying switches is the method of actuation; that is, toggle, pushbutton,

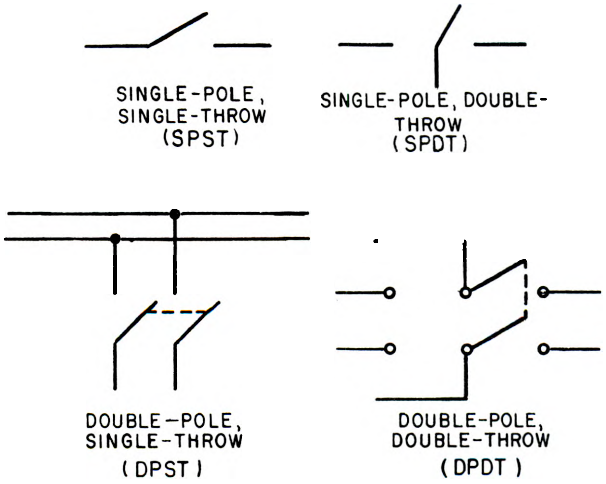
SINGLE-POLE, SINGLE-THROW (SPST)
SINGLE-POLE, DOUBLE-THROW (SPDT)
DOUBLE-POLE, SINGLE-THROW (DPST)
DOUBLE-POLE, DOUBLE-THROW (DPDT)

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Figure 6-10.–Schematics of commonly used switches.

precision, and rotary types. Further classification can be accomplished by a description of switch action such as on-off, momentary on-off, on-momentary off, etc. Momentary contact switches hold a circuit closed or open only as long as the operator deflects the actuating control.

Manually Operated Switches

One of the most common types of aircraft switches is the toggle. Toggle switches have their moving parts enclosed. A double-pole, double-throw, on-off-on toggle switch is shown in figure 6-11. These switches have many uses and are used especially for applying power to various circuits. They are often provided with a luminous tip on the lever so as to be visible in the dark.

Pushbutton switches have one or more stationary contacts and one or more movable contacts. The movable contacts are attached to the pushbutton by an insulator. These switches are usually spring loaded and are of the momentary contact type. They have many uses, such as indicator light checks and circuit reset. The push-on and push-off type switch is seldom used in naval aviation.

A rotary selector switch may perform the functions of a number of switches. As the knob of a rotary selector switch is rotated, it opens one circuit and closes another. This can be seen from an examination of figure 6-12. Some rotary switches have several layers of wafers. By adding wafers, the switch can be made to operate as a large number of switches. Ignition switches and voltmeter selector switches are typical examples of this type.

Mechanically Operated Switches

Mechanically operated switches are used in many types of installations, such as radar limit switches for antenna throw, as interlock switches to disable the power to equipment when removing the case, and as communication transceiver control box switches. Many of these are the precision, snap-acting switches found in all aircraft. They are widely used because of their small size, light weight, and excellent dependability. (The term Micro switch, although frequently used in referring to all switches of this type, is a trade name for the switches made by the Micro Switch Division of the Minneapolis Honeywell Regulator Company.)

These switches will open or close a circuit with a very small movement of the tripping device (1/16 inch or less). They are usually of the pushbutton variety, and they usually depend on one or more springs for their snap action. For example, the heart of the Micro switch is a beryllium copper spring, heat-treated for long life and unfailing action. The simplicity of the one-piece spring contributes to the long life and dependability of this switch. The basic Micro switch is shown in figure 6-13.

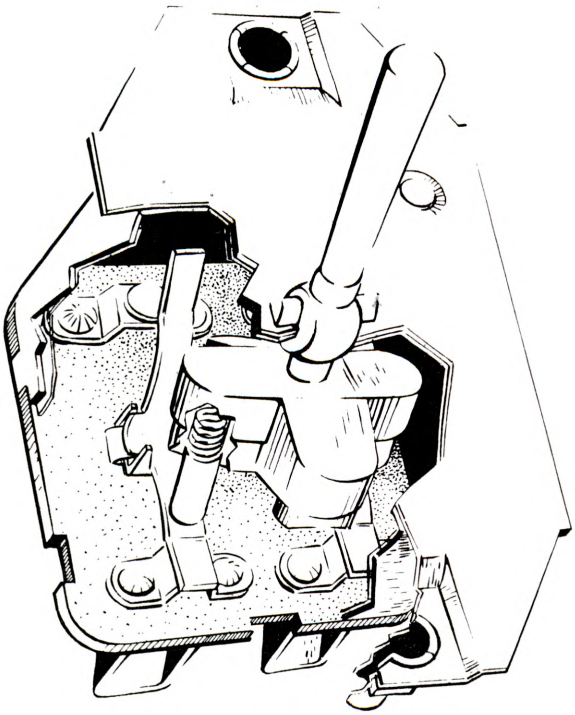
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Figure 6-11.—Toggle switch.

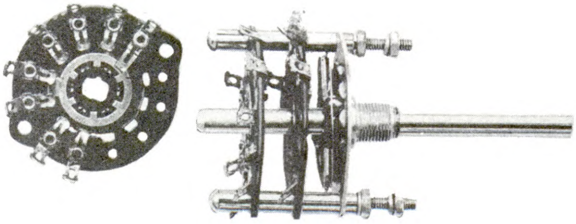
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Figure 6-12.—Rotary selector switch.

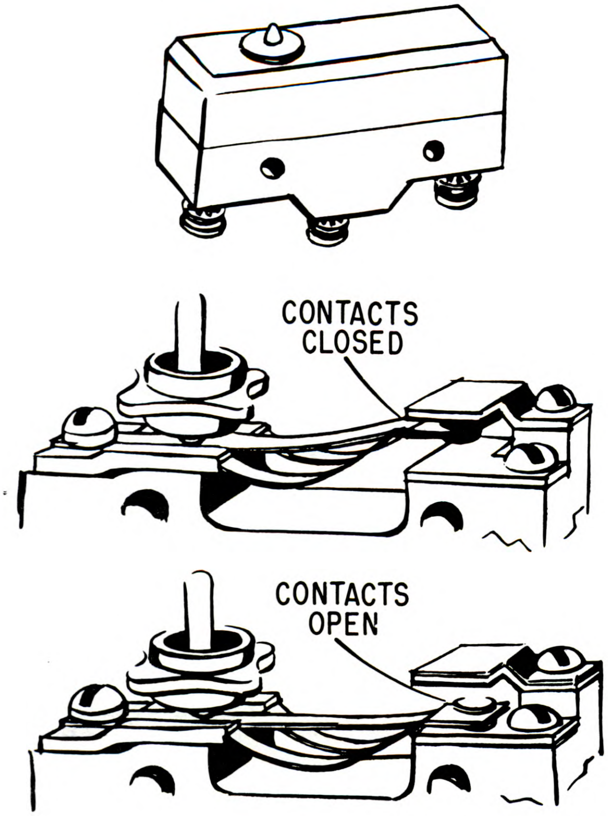

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Figure 6-13.—Micro switch.

The versatility of the snap-action switch is indicated in figure 6-14, which shows how the basic switch may be used with different type enclosures and actuators. The particular type of switching unit used depends upon the function it is to perform and upon environmental conditions. Figure 6-14(A) shows a lightweight aluminum enclosure which may contain one or more plastic-enclosed basic switches. The plastic enclosure provides electrical insulation between the housing and the live electrical parts, support for the terminals, and a dusttight box around the electrical contacts.

Figure 6-14 (B) shows one of the various types of switch actuators used with basic switches when complete enclosures are not needed. They provide a means for protection and mounting of the switch. They relay the operating motion from a cam or slide to the basic switch in a way that assures long life and dependability. Figure 6-14 (C) shows a toggle switch which uses one or more of the basic subminiature switches. These subminiature switches are smaller than the conventional Micro switch and are finding wide use in various switching arrangements.

Pressure-operated switches usually have Bourdon tubes, syphons, or diaphragms against which fluid operates to actuate the switch. Some low-frequency transmitters use pressure switches to reduce transmitter power at high altitude (and thus prevent arcing).

Thermal switches usually incorporate a bimetallic sheet that bends or snaps at a desired temperature to actuate the switch. They are used extensively as circuit breakers and also find application in controlling the igniter circuit on heaters, and in operating signal lights at critical temperatures.

Maintenance

While the switch itself is relatively simple to check, it sometimes offers difficulty in maintenance because of its location in inaccessible places. After a visual inspection of the connections and the switch, a continuity test will indicate any malfunctions. When the switch mechanism is found to be defective, it normally is not repairable and therefore should be replaced.

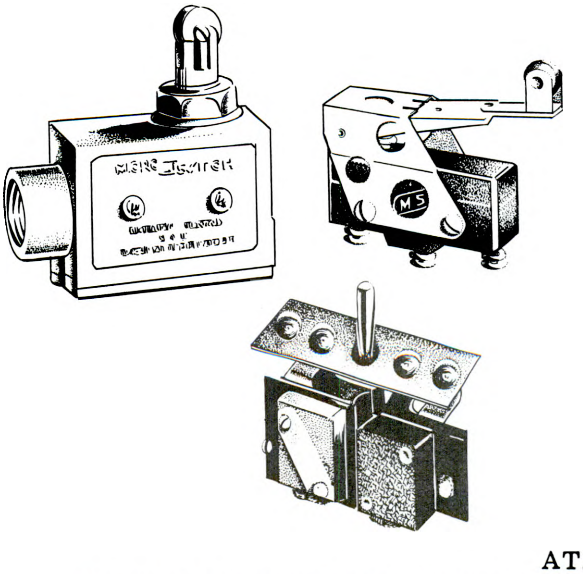

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Figure 6-14.—Snap-action switching units.

When enclosed switches are used, failure to seal properly around cable openings is the most common cause of trouble. Altitude changes permit "breathing" of moist air into enclosures within the switch enclosure. The condensation can short across the switch terminals, or it can corrode the switch actuators and make them inoperative. This problem can be eliminated by carefully sealing the openings, or by using hermetically sealed switches. (Hermetic sealing will also prevent dust and dirt from reaching the contacts and thereby reduce the possibility of high resistance shorts and open circuits.)

Some switches are damaged during installation, particularly those with plastic housings. Proper care in installing or replacing plastic-enclosed switches will help to eliminate this type of trouble.

Some switch assemblies are equipped with adjustments which enable them to operate at a preset temperature, pressure, position, etc. Caution should be exercised in making these adjustments; if they are not accurate, damage to the switch or to the equipment can result.

RELAYS

Types

Relays are electrically operated control switches, and are classified according to their use as control relays or power relays. Control relays are usually known simply as relays; power relays are called contactors. Power relays control the heavy power circuits of the aircraft electric system.

The function of a control relay is to take a relatively small amount of electrical power and use it either to signal or to control a large amount of power. Where multipole relays are used, several circuits may be controlled simultaneously.

The use of relays saves space and weight in the aircraft by permitting the use of small switches at remote control stations. The relays permit the operator to control large amounts of current at other locations in the aircraft, and the heavy power cables need to be run only to the point of use. Only lightweight control wires are connected to the control switches. Safety is also an important reason for using relays, since high power circuits can be switched remotely without danger to the operator.

Control relays, as their name implies, are frequently used in the control of low power circuits or other relays, although they also find many other uses. Electron tube plate current relays can control the larger currents necessary to operate electrical devices. In automatic relaying circuits, a small electric signal may set off a chain reaction of successively acting relays, which then perform various functions. Control relays can also be used in so-called "lockout" action to prevent certain functions, such as the firing of rockets, from occurring at the improper time. Electrical operations which must not occur simultaneously can be "interlocked" by control relays. Another important function of control relays in aircraft equipment is for "sensing" undervoltage and overvoltage, reversal of current, excessive currents, phase and amplitude, polarity, etc.

Another possible classification of relays is open, semisealed, or sealed. Semisealed relays have protective covers which are installed with gaskets to prevent entrance of salt, dust, and foreign material into the contact or mechanism area. These relays are still considered satisfactory for certain applications in present-day aircraft.

For most applications in today's high altitude, high speed aircraft, however, it is necessary to go beyond the protection offered by semisealed relays. When such relays are used, quick changes in altitude, humidity, and temperature can cause condensation of moisture within the unit. Subsequent low temperatures may then freeze the moisture on the contactor.

Hermetically sealed relays were developed to answer the demands of most modern aircraft equipment. A true hermetic seal is generally considered one that is metal to metal or glass to metal. Plastic or plastic-rubber type gasketed seals are not generally considered true hermetic seals. However, both semisealed and hermetically sealed relays are used. In some applications a gasket sealed relay may be adequate, but the true hermetically sealed type is generally considered to be more desirable. In addition to being independent of altitude changes, the hermetically sealed relay also has the advantage of being protected from improper adjustments.

Operation

In general, the basic components of a relay are the coil (or solenoid), the iron core, the fixed and movable contacts, and the mounting (and if sealed, the can). A manual switch, limit switch, or other small control device starts and stops the flow of current to the coil. The flow of electric current through the coil creates a strong magnetic field around and within the coil. This magnetic field moves a clapper or plunger which completes the magnetic circuit. Figure 6-15 (A) shows a basic single coil clapper type relay. The dashed lines indicate the magnetic lines of flux. For a more complete analysis of magnetic theory and basic relay operation, see Basic Electricity, NavPers 10086-B.

The second basic type of relay is the rotary (fig. 6-15 (B)). Although this type of construction is not as common as the clapper type, the rotary type has greater vibration and shock resistance than the others. Their main disadvantage is that they are somewhat sluggish and require higher operating power. The rotary relay operates on the principle of an electric motor, but turns through only a small angular arc. The problem of hanging contacts on such a mechanism is a difficult one, and therefore the use of these devices is limited. When used with standard wafer switch assemblies, this type of relay provides a means for assembling a switching device of any degree of complexity.

Some relays operate from an a-c supply. A-c relays depend upon the same fundamental principles as the d-c relay; that is, magnetic fields. When alternating current is applied to an electromagnet, the current passes through zero twice every cycle. Since the pull on the armature is proportional to the current through the electromagnet, the armature tends to open every time the current nears zero, causing the relay to chatter. To prevent this, shading coils (sometimes called shaded poles) are used.

A shading coil consists of a copper band or stamping which is short-circuited and embedded around part of the electromagnet pole face. By being placed around part of the pole face, it acts as a shorted transformer secondary. The current in the main coil lags the applied voltage by approximately 90°; the flux is in phase with the current. The voltage of the shading coil is an induced voltage, and it lags the current in the main coil by 90°. Since the shading coil acts like a shorted secondary (resistive), the current in the shading coil is in phase with the induced voltage. Therefore, the magnetic field of the shading coil lags the magnetic field of the main coil by 90°. Flux continues to exist in the electromagnet even when the main coil current becomes zero; thus chattering is prevented.

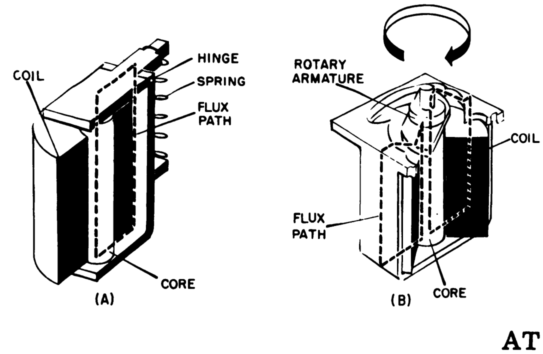

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Figure 6-15.—Basic types of relays.

Relay contacts are arranged in many different forms. Usually the number and sequence of switching operations to be performed dictates the contact arrangement.

It is often desirable to introduce time delays by use of relays. One method is to use a thermal relay for a time delay. The operation of this type relay is similar to that of the thermal circuit breaker, with the exception that it closes the circuit (rather than opens it), when heated. Due to the simplicity of the mechanism, it can be made very small and can be hermetically sealed, making it ideal for use in aircraft. Because the thermal relay is activated by heat, it can be used on either a.c. or d.c.

Maintenance

The relay is one of the most dependable electromechanical devices in use; but like any other mechanical or electrical device in aircraft equipment, relays occasionally wear out or become inoperative for one reason or another. Should an inspection determine that a relay is defective, the relay should be removed immediately and replaced with another of the same type. Care should be exercised in obtaining the same type replacement because relays are rated in voltage, amperage, type of service, number of contacts, continuous or intermittent duty, and similar characteristics.

Relay coils usually consist of a single solenoid. If a relay fails to operate, the coil should be tested for open circuit, short circuit, or ground. An open coil is a common cause of relay failure.

The formation of film on the contact surfaces of a relay may be considered as another principal cause of relay trouble. Although film will form on the contacts by the action of atmospheric and other gases, grease film is responsible for a lot of contact trouble. Carbon formations, caused by the burning of a grease film or other substance (during arcing), also can be troublesome because carbon forms rings on the contact surfaces. As the carbon rings build up, the relay contacts are held open.

When current flows in one direction through a relay, the contacts may be subjected to an effect called "cone and crater." The crater is formed by the transfer of the metal of one contact to the other contact, the deposit being in the form of a cone.

Some relays are equipped with ball shaped contacts. In many applications this type of contact is considered superior to the flat surface. Dust or other substances are not as readily collected on a ball shaped surface. In addition, a ball shaped contact can penetrate film more easily than a flat contact. When cleaning or servicing ball shaped relay contacts, extreme care must be taken to avoid flattening or otherwise altering the contact's rounded surfaces.

Under normal operating conditions, most relay contacts spark slightly; however, this type of sparking must not be confused with the spitting and arcing which causes burning and pitting of the contacts.

All relays require maintenance and care. Contact clearances or gap settings must be maintained in accordance with the relay's operating specifications. Relay contact surfaces must be kept clean and in good operating condition.

For detecting potential relay trouble during preventive maintenance, the following guides are suggested: Check for charred or burned insulation on the relay and for darkened or charred terminal leads coming from the relay. Both of these indicate overheating. If there is even a slight indication that the relay has overheated, it should be replaced with a new relay of the same type. Overheating is sometimes caused by the power terminal connectors not being tight enough; screw connections should always be checked during preventive maintenance.

NOTE: Life of relays may be increased by removal of a light film buildup with recommended spray contact cleaner and lubricant.

Extreme care should be taken in removing and replacing covers on semisealed relays. The entry of dust or other foreign material may cause contact discontinuity. When the relay is installed in a position where there is a possibility of contact with fuel fumes, extra care should be taken with the cover gasket. Any damage to the gasket, or incorrect seating of the gasket, increases the possibility of igniting vapors.

AUXILIARY POWER SOURCES

The electric power requirements for starting and servicing modern aircraft are very high. Even in those aircraft which have batteries installed, routine servicing and operational testing of the electronics system require that either the aircraft engines be operating or that an external source of electric power be used.

There are many auxiliary power units (APU's) available for supplying electric power to the aircraft for engine starting, ground servicing, and operational testing. External power receptacles are mounted on all aircraft to provide a means of connecting the external sources to the aircraft.

Some aircraft are also furnished with an airborne auxiliary powerplant (APP) installed aboard or attached externally to the aircraft. The auxiliary powerplant usually consists of an independently operated gasoline engine or turbine which drives a generator. The generator supplies power to the electric system on the ground and in the air. Although the airborne auxiliary powerplant is not capable of supplying the entire load requirements for normal operation of all equipment, it does have the capacity to furnish limited loads for ground servicing or for emergency use in flight.

This section presents a brief discussion of batteries, ground- and ship-based auxiliary power units, airborne auxiliary powerplants, and the main power sources normally found in aircraft hangars and on carrier flight decks.

BATTERIES

The function of the aircraft storage battery is to provide an emergency source of electrical power for operating the electrical systems of an aircraft. The battery also functions in such a manner that it eliminates the commutator ripple produced by the d-c generator. During normal aircraft operation, the generator supplies the primary source of electrical energy, and maintains the battery in a charged state. The battery supplies power to the aircraft only when the speed of the engine or gererator drive system becomes so slow that the generator's output voltage falls below the battery voltage.

The battery is the emergency power source for the aircraft. Therefore, the battery should never be used for starting engines or servicing equipment if another source of power is available. Such unnecessary usage tends to shorten the life of the battery and keeps the battery in poor condition to meet emergency operation requirements. During the periods when the engines are idling or being started, the electrical loads should be kept at a minimum. The service life of the aircraft battery depends a great deal upon the frequency and quality of care it is given. Batteries that are abused or that receive careless treatment and servicing generally have their service life ended prematurely.

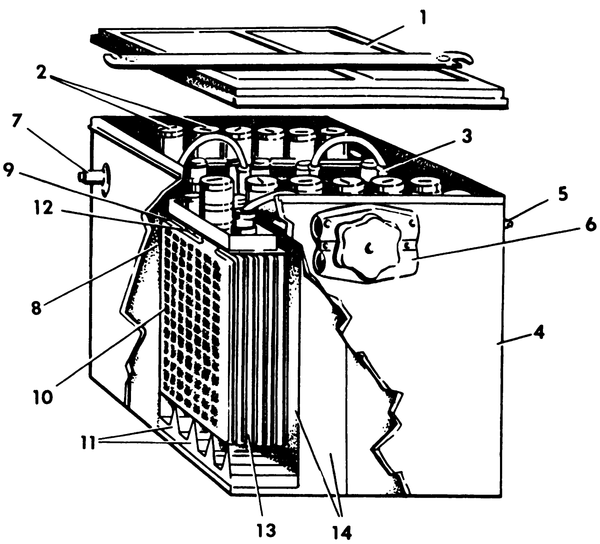
Since it is important to keep their weight at a minimum, aircraft batteries have a small capacity. Consequently, they must be used with great care.

Most aircraft batteries are equipped with a quick-disconnect unit as shown in figure 6-16 This unit is a heavy-duty connector with a handle attached to a threaded post. The battery cables can be disconnected from the battery post simply by turning the handle and pulling the quick-disconnect unit.

Lead-Acid

The most common aircraft battery in use today is the lead-acid type. However, two recent types, which are known as the nickel-cadmium and the silver-zinc batteries, are being used in some aircraft.

Fundamentally, there is no difference in the operation of the lead-acid aircraft battery and the lead-acid automobile battery. Both types of batteries have their plates immersed in a solution of sulfuric acid and water and operate on the same basic principles. Batteries are covered in more detail in chapter 3 of Basic Electricity, NavPers 10086-B.



1. Metal cover.
2. Filler cap and vent plugs.
3. Cell connectors.
4. Metal container.
5. Vent.
6. Quick-disconnect receptacle and plug.
7. Vent.
8. Cell container.
9. Positive plate group strap.
10. Plate.
11. Plate supports.
12. Negative plate group strap.
13. Separators.
14. Cells.

AT.59

Figure 6-16.—Typical aircraft lead-acid storage battery.

Aircraft batteries require a great deal more care than automobile batteries because of the unusual conditions under which they operate. The aircraft battery is usually shielded by enclosing it in a grounded, metal housing. (See fig. 6-16.) This completely shields the battery and the terminal connections. This shielding eliminates, to a large degree, radio-frequency interference from being induced into the communication system from the battery and its associated components.

Nickel-Cadmium

Some nickel-cadmium batteries used in naval aircraft are physically and electrically interchangeable with the lead-acid type, while some are sealed units which use standard plug and receptacle connections which are used on other electrical components. These batteries generally require less maintenance throughout their service life.

The electrolyte used in nickel-cadmium batteries is a solution of potassium hydroxide. This solution is very caustic and will burn clothing, skin, etc.

The nickel-cadmium battery performs especially well at high discharge rates and at low temperatures.

Silver-Zinc

Silver-zinc batteries are used largely in military applications and in some industrial applications where their unique characteristics are sufficiently important to justify their comparatively high cost. These batteries are currently installed in various models of Navy helicopters.

The silver-zinc battery was developed for one major and one secondary purpose. The major purpose was to secure a large quantity of electrical power for both ground and emergency flight operations. The secondary purpose was to permit a design weight savings in new aircraft. A lightweight, silver-zinc battery provides as much electrical capacity as a much larger lead-acid or nickel-cadmium battery.

The battery's high electrical capacity per unit of space and weight is a result of the close plate spacing, the large degree to which the active plate materials are utilized, and the absence of heavy supporting grids in the plate. Silver-zinc batteries are capable of producing as much as six times more energy per unit of weight and volume than other types. Silver-zinc cells have been built with capacities ranging from tenths of ampere-hours to thousands of ampere-hours.

Silver-zinc batteries have a maximum service cycle life which is less than that of other types, but their life expectancy compares favorably with that of other types of batteries that are designed for maximum capacity per unit of space and weight such as nickel-cadmium.

AUXILIARY POWER UNITS

In this discussion the term auxiliary power unit is limited to those units which are portable, but are not installed aboard the aircraft. The units may be self-propelled, towable, or merely transportable; they may use diesel fuel, jet fuel, or gasoline. The generators may be driven by the unit's engine or it may have its own prime mover. Several types are discussed; however, before beginning a discussion of specific types of individual models, several generalizations should be mentioned.

When moving the APU into the vicinity of the aircraft, care should be taken to avoid collision with aircraft or other equipment. Flight lines and aircraft parking areas are normally crowded, and space between aircraft and equipment may not be sufficient to allow passage of the APU. Equipment and/or aircraft may have to be moved and repositioned to permit access to the aircraft to be serviced. When movement of the aircraft is necessary, the line crew should be notified, and requirements should be outlined. Local procedures and policies must be followed, and line safety regulations observed. Under NO conditions should the APU be used to move the aircraft, not even "a couple of feet."

Once access to the aircraft has been gained, the APU must be connected to the aircraft. Each unit has its own procedures for operation, but some general considerations apply to all. Prior to connecting the APU to the aircraft to be serviced, all aircraft power switches should be checked and placed in the proper position. (This requires familiarization with the aircraft; the information is available in the Flight Manual and in the Maintenance Instructions Manual for each model aircraft.)

Prior to making the actual connection, the cable and the receptacle should be inspected carefully for general condition and for correct polarity/phase. Many flights are aborted because external power cables have been inserted into aircraft with polarity or phase reversed due to careless insertion or defective cables.

The APU should not be connected to the aircraft with a "hot line"; the generator power switches should be off. After connection, the generator may be activated, and the switches turned on when stable operation is obtained.

During high load operation of APU's, the power cables frequently heat excessively and the cable voltage drop is quite noticeable. Nearly all of the mobile electric power plants (MEPP's) have an output current capability well in excess of the current rating of the cables. Therefore, when supplying power to large loads, the current ratings of the cables must be considered. If the load requirements exceed the rating of the cable, the load should be reduced or a higher capacity APU should be obtained.

Mobile Electric Powerplants

NC-10 AND NC-10A.–The NC-10 and NC-10A powerplants are diesel engine-driven mobile powerplants, designed to supply 90 kva at 115/200 volts, 3-phase, 400 Hz for servicing, starting, and maintaining helicopters and jet aircraft. A portion of the generated electric power is rectified to supply 28 volts d.c. at 750 amperes (1,000 amperes intermittent) for aircraft starting.

The powerplant is enclosed in a steel housing, fabricated in two sections which are easily removed for servicing of the unit. Operating components are mounted on a four-wheel trailer, which is equipped with mechanical type internal expanding front wheel brakes. The brakes may be set by a hand lever or automatically set when the tow bar is in the vertical position.

Double hinged doors provide access to the control panel, starting components, and three output power cables.

The plant's electrical system is protected from overload by output circuit contactors, circuit breakers, over- and under-voltage relays, over- and under-frequency relays, thermal overload relays, and fuses.

The NC-10 powerplant was designed for use on carriers and shore stations. The NC-10A (fig. 6-17) was especially designed for Marine Corps shore duty activities. The operating features and technical data are the same for both plants, except that the NC-10A employs a self-propelled feature.

NC-12 AND NC-12A.–The NC-12 and NC-12A are diesel engine-driven powerplants, designed to supply 125 kva at 115/200 volts, 3-phase, 400 Hz for servicing, starting, and maintaining helicopters and jet aircraft. A portion of the generated electric power is rectified to supply 28 volts d.c. at 750 amperes (1,000 amperes intermittent) for aircraft starting. These units utilize dual power output circuits which make them capable of simultaneously delivering electric power for two P-3A aircraft.

The powerplants and components are mounted on a four-wheel trailer, equipped with mechanical front wheel brakes which are actuated by a hand lever or the spring-loaded tow bar. These units do not come equipped with self-propelled features; they must be towed.

The NC-12 AND NC-12A are similar except the NC-12 was designed for shore duty operation, while the NC-12A was designed for either carrier or shore-based use. The electrical characteristics are identical. Figure 6-18 depicts the NC-12A.

The technician will come in contact with many new types of powerplants such as the NC-10 series and NC-12 series, which will eventually replace the older plants such as the NC-5, NC-6, and NC-7 series.

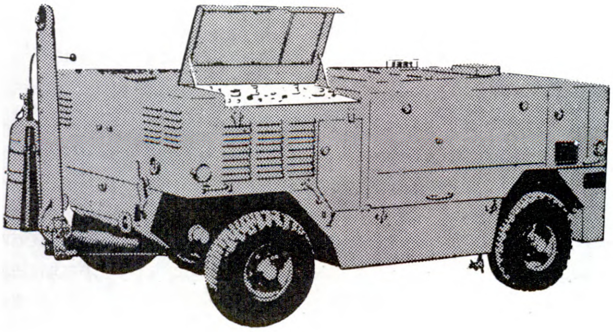


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Figure 6-17–Mobile Electric Powerplant Type NC-10A.

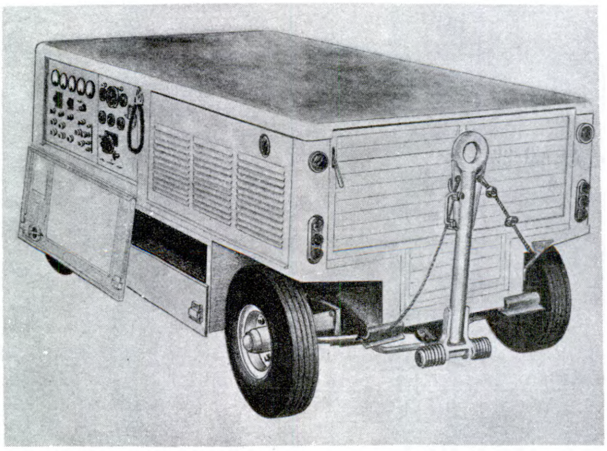

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Figure 6-18.–Mobile Electric Powerplant Type NC-12A.

(NOTE: Most naval air stations and activities have training courses available to provide instruction in the use and operation of mobile powerplants, only licensed operators should operate this type equipment.

Table 6-1 shows a comparison of the major characteristics of the mobile electric powerplants discussed in the preceding paragraphs, as well as some older types still in common usage.

AIRBORNE AUXILIARY POWERPLANTS

Some of the larger aircraft are equipped with auxiliary powerplants installed at different locations on different aircraft. They are used to furnish electric power when engine-driven generators are not operating or when external power is not available. Aircraft auxiliary powerplants are particularly useful on seaplanes, which are often moored to buoys for long periods of time. Mooring lights must be on and communications equipment used while moored. The APP is utilized to furnish power since excessive battery usage must be avoided.

Another particular application for the powerplants is in large land-based aircraft. Here they are used to provide a constant voltage at a constant frequency. This is advantageous because the output of the APP is not dependent on aircraft engine rpm.

Some of these units use a gasoline engine to drive the generator, while others use a gas turbine. Figure 6-19(A) shows a gasoline engine-driven APP; figure 6-19(B) shows a gas turbine type.

Auxiliary powerplant logbooks must be kept on each powerplant. The operator of the powerplant is responsible for entering the operating time in the log each time the powerplant is used.

RECTIFIER UNITS

The use of a-c generators for primary electrical power in modern naval aircraft has been mentioned previously. One of the reasons for this is the saving in weight.

The size of wire required to deliver a given wattage can be considerably smaller, if the voltage is 115 volts a.c. rather than 27.7 volts d.c. Due to higher voltage and a four-wire (grounded neutral) system, the current carried in each wire is only a fraction of that required for the same power in a 28-volt d-c system. This permits the use of much smaller aircraft wiring with a great saving in weight. The a-c generator itself, especially in the larger sizes, is lighter than a d-c generator of comparable output. Many of the components for system control and protection are also lighter than comparable d-c components.

Even though the d-c generator is eliminated by the utilization of a.c. as a primary source of power, d-c voltages are required for proper functioning of many systems. This d-c voltage is obtained from a transformer-rectifier assembly.

Figure 6-20 is a schematic drawing of a transformer-rectifier unit. The transformer is a 3-phase, 400 Hz, stepdown type. The input is 115 volts a.c. to a delta connection, and the output is 22 volts a.c. across each leg of a wye connection. The rectifiers are of the selenium dry disk type, forming a bridge unit. After rectification (and minus the voltage drop across the rectifier), the output is 28 volts d.c. (Refer to chapter 16 of Basic Electricity, NavPers 10086-B for discussion of 3-phase power components.)

DECKEDGE POWER

The primary function of the deckedge electrical power system installed on aircraft carriers is to provide a readily accessible source of servicing and starting power to aircraft at almost all locations on the carrier's flight and hangar decks.

The 28-volt d.c. is supplied by motor-generators or rectified a.c. from remote a-c generators.

The 400 Hz, 3-phase a-c servicing voltage is usually supplied by these same a-c generators through stepdown transformers. Figure 6-21 shows a diagram of an electrical system which may be found on a modern carrier. The deckedge power may be supplied by service outlets at the edge of the flight deck or from recesses in the flight deck. All systems have standard remote control switches, service outlet boxes, and portable cables. Figure 6-22 shows a typical deckedge installation.

Table 6-1. —Characteristics of mobile electric powerplants.

Type	Methods of propulsion	Generator drive	Operating environment	Power ratings		Starting Power		Service power	
				d. c.	a. c.	Jet	Recip.	Jet	Recip.
NC-5, NC-5A, NC-5B	Self-propelled gasoline engine vehicle	Main vehicle engine	Shore based only	28/35v 200/500a 1000a int	115/200v 400 Hz, 3Ø 30/45 kva	d. c. only	d. c. only	a. c. d. c.	a. c. d. c.
NC-6, NC-6A	Towed trailer	Gasoline engine	Shore based only	28.5v 200a 32/45 kw	120/208v 400 Hz, 3Ø 30 kva	DNA	DNA	a. c. d. c.	a. c. d. c.
NC-7, NC-7A, NC-7B, NC-7C	Towed trailer, or self-propelled within narrow limits	Gasoline engine	Shore based only	28.5v 750a 1000a int 45 kw	115/200v 400 Hz, 3Ø 35 kva 0.75 PF	d. c. only	d. c. only	a. c. d. c.	a. c. d. c.
NC-10	Towed trailer	Diesel engine	Shore or carrier based	28v 750a 1000a int	115/200v 400 Hz 90 kva	d. c. only	d. c. only	a. c. d. c.	a. c. d. c.
NC-10A	Towed trailer or self-propelled	(same)	(same)	(same)	(same)	(same)	(same)	(same)	(same)
NC-12	Towed trailer	Diesel engine	Shore based only	28v 750a 1000a int 45 kw	115/200v 400 Hz 125 kva	d. c. only	d. c. only	a. c. d. c.	a. c. d. c.
NC-12A	(same)	(same)	Shore or carrier based	(same)	(same)	(same)	(same)	(same)	(same)

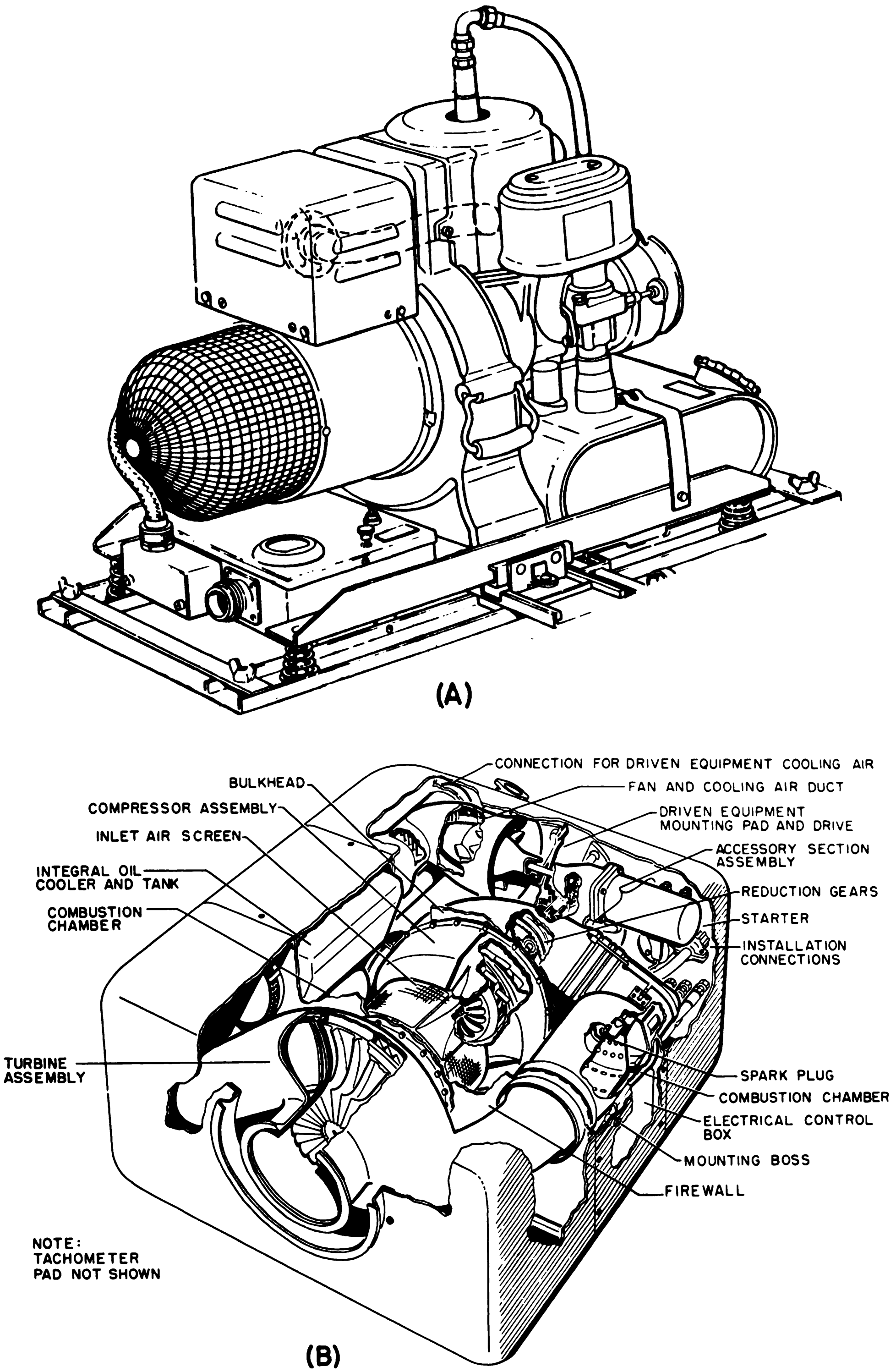

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Figure 6-19.—(A) Gasoline engine-driven APP; (B) gas turbine type APP.

Although there are some variations between carriers of different classes and aircraft of different models, this discussion and the associated figures represent a typical example. For explicit details concerning a specific installation, check the deckedge station and its power cables.

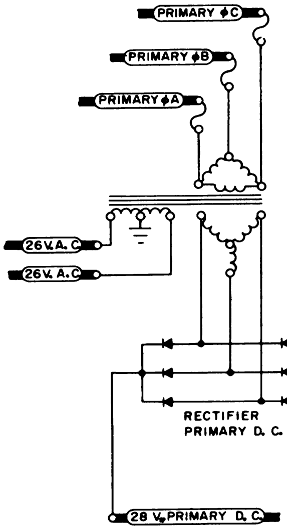

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Figure 6-20.—Transformer-rectifier.

The d-c service outlet box contains two male plugs. One is rectangular in shape and the other is oval. The rectangular plug provides servicing power and the oval plug provides starting power for aircraft with electrical starters.

The aircraft is equipped with an oval-shaped plug for applying d-c servicing power and a rectangular-shaped six-pin plug for applying 3-phase, 400 Hz, a-c servicing power. Power is applied to the aircraft by connecting the portable cables between the deckedge and aircraft plugs. To obtain d-c servicing power, the oval end of the portable cable is connected to the oval plug in the aircraft and the opposite (rectangular) end is connected to the rectangular deckedge plug.

To obtain 3-phase, 400 Hz, a-c service power, the portable a-c plug is connected to the aircraft and the opposite end to deckedge a-c service power box. The ends of the a-c portable cable are interchangeable.

Figure 6-23 illustrates how these connections may be made. To obtain d-c servicing

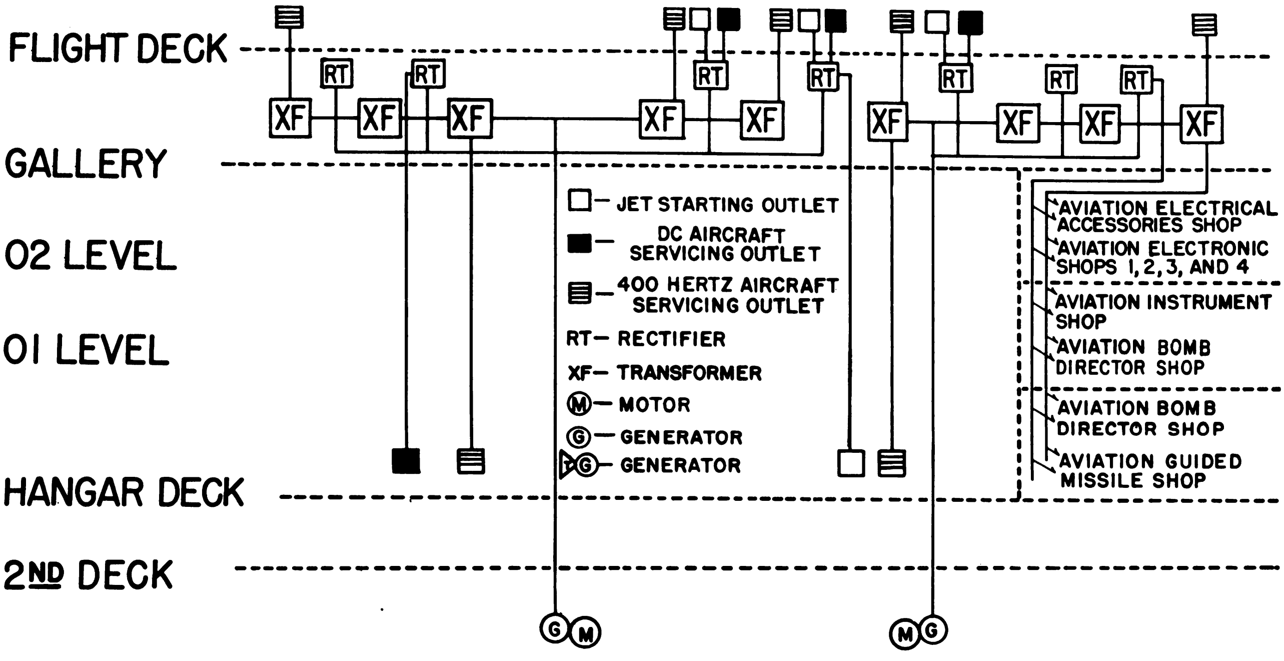
FLIGHT DECK
GALLERY
02 LEVEL
01 LEVEL
HANGAR DECK
2ND DECK
RT
XF
☐— JET STARTING OUTLET
■— DC AIRCRAFT SERVICING OUTLET
▤— 400 HERTZ AIRCRAFT SERVICING OUTLET
RT— RECTIFIER
XF— TRANSFORMER
Ⓜ— MOTOR
Ⓖ— GENERATOR
Ⓖ— GENERATOR
AVIATION ELECTRICAL ACCESSORIES SHOP
AVIATION ELECTRONIC SHOPS 1, 2, 3, AND 4
AVIATION INSTRUMENT SHOP
AVIATION BOMB DIRECTOR SHOP
AVIATION BOMB DIRECTOR SHOP
AVIATION GUIDED MISSILE SHOP
G M
M G

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Figure 6-21.–Deckedge electrical system.

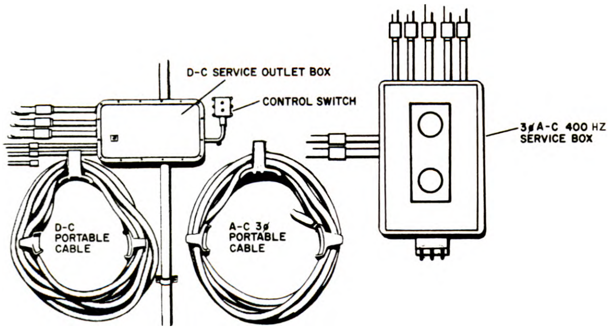

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Figure 6-22.–Typical deckedge installation.

power to the aircraft, connect the cable from A to A'; to obtain a-c service power connect it from B to B'.

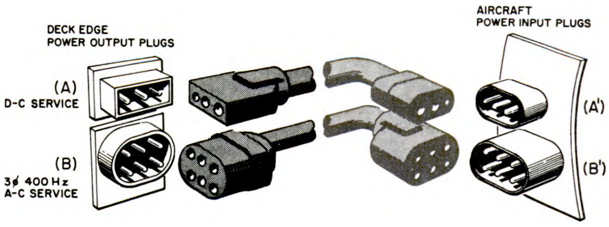
The a-c service power is usually provided at the same station as the d-c power. The cable is usually permanently attached to the service outlet box. Although its plug is rectangular, there is no danger of connecting it to the d-c service power receptacle as the size and number of pins are not the same.

Care should be exercised when connecting auxiliary power cables to the aircraft. The cables are heavy, and damage to the aircraft may result if there is not sufficient slack in the cables.

GROUND COOLING SYSTEMS

The purpose and need for ground cooling will vary with type of aircraft and climatic conditions. When repairing high-voltage equipment aboard large aircraft in a tropic zone, ground cooling of the aircraft cabin reduces the hazard of shock due to clothing being wet with perspiration. It may also prevent shorting of components by falling perspiration.

An additional reason for using ground cooling equipment, even in temperate zones, is the fact that electronic equipment produces large quantities of heat. This heat must be dissipated or the equipment would achieve temperatures that could cause damage and create a fire hazard.


DECK EDGE POWER OUTPUT PLUGS
AIRCRAFT POWER INPUT PLUGS
(A) D-C SERVICE
(B) 3ø 400 Hz A-C SERVICE
(A')
(B')

AT.67

Figure 6-23.–D-c and a-c power cables and plugs.

The combination of tropic heat and equipment heat in an aircraft without a cooling system operating often creates a hazard of heat-stroke or heat exhaustion. When the aircraft is airborne, various means are used to accomplish the required cooling. Some electronic equipments have fans built in for cooling. Others generate so much heat that a blast of air from outside the aircraft must be used. Some large magnetrons are liquid cooled–the liquid, in turn, is cooled by air directed over a radiator.

When a large quantity of air is required for cooling, a common source for the air is the aircraft's ventilation system. However, line maintenance, ground operational checks, and functional checks are usually performed without the aircraft's ventilation system operating, since this system is driven by the aircraft engines. Therefore, a substitute air supply must be provided for the air distribution system.

The air distribution system illustrated in figure 6-24 consists of two subsystems. One subsystem controls and distributes the incoming fresh air supply; the other controls exhaust airflow through electronic racks and tactical crew station cabinets to the atmosphere. The fresh air distribution subsystem is designed to use fresh, temperature-controlled air from two engine-driven cabin air compressors. An alternate source of unconditioned fresh air, called the auxiliary ventilation system, may be used in flight to supplement the temperature-controlled air from the cabin air compressors.

The auxiliary ventilation system receives air from a ram air inlet. This inlet and a ground air connection are adjacent to one another in the nosewheel well and connect to a

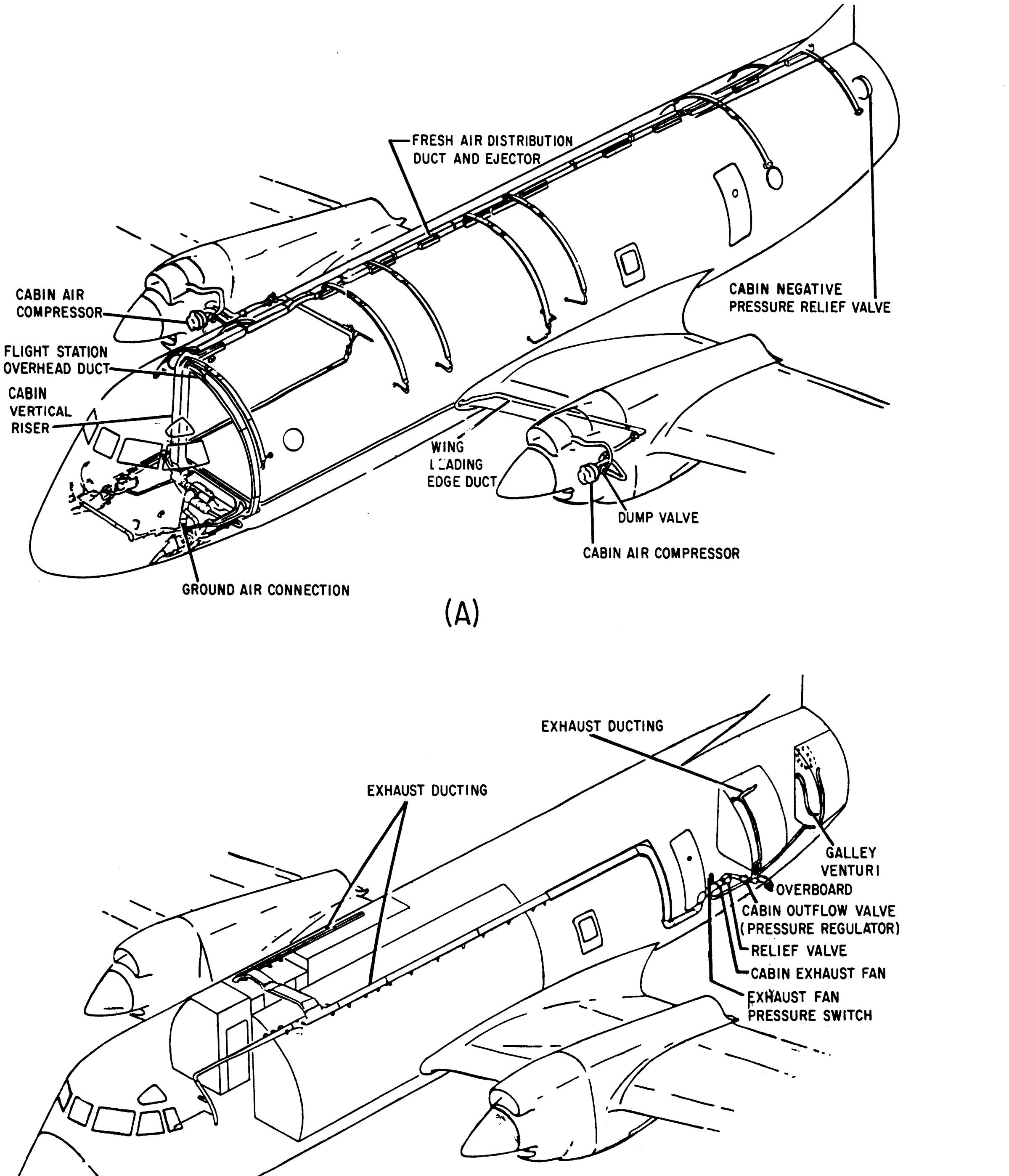


Figure 6-24.–Air distribution system of an aircraft. (A) Inlet air system; (B) exhaust air system. AT.68

common duct. This duct connects to the duct which normally carries air from the cabin air cycle cooling system to the cabin air riser (vertical duct). The air from either of these alternate fresh air sources is routed the same as air coming from the cabin air cycle cooling system. Therefore, the ground connection permits the output from a mobile air conditioner to be routed through the duct which normally carries air from the cabin air cycle cooling system. This is particularly desirable for line maintenance purposes.

ACM-2905-F22

The ACM-2905-F22 is a mobile aircraft air conditioner that is capable of delivering 21.9 tons of refrigeration at 2,500 cfm (cubic feet per minute). A ton of refrigeration is the amount of cooling resulting from the absorption of enough heat to melt a ton of ice at 32° F in a 24-hour period. This is equivalent to a cooling capacity of approximately 12,000 Btu per hour.

The air conditioning unit consists of a 7-cylinder, 40-ton radial compressor directly connected to a 150-hp internal combustion engine; large cooling coils; and an evaporative condenser. (See fig. 6-25.) The engine uses conventional automotive type electrical starting and battery charging equipment.

The unit is housed in a 12-foot truck body and is controlled from a simple panel located on the outisde of the truck for ease of operation. (See fig. 6-26.)

A built-in safety system cuts off the ignition to the air-conditioning unit whenever the following conditions occur:

1. Loss of engine oil pressure.
2. Engine water termperature too high.
3. Compressor suction pressure too low.
4. Compressor discharge pressure too high.

Should any of these conditions occur, an alarm bell will sound, a red light on the control panel will be illuminated, and the engine will automatically shut down.

The control panel, mounted in the left side of the unit, contains the following instruments and controls:

1. Panel lights and switch. Two panel lights are supplied to provide illumination for the control panel.

2. Interior light switch and pilot light. This switch is provided to operate lights situated at other points in the installation. The green pilot light indicates when the interior lights are on.

3. Safety release switch. This is a push-button switch which is used to remove the safety controls from the circuit. Should a shutdown occur due to excessively high water temperature, it might be necessary to hold this button in while starting the engine after the cause of the shutdown has been corrected.

4. Key ignition switch. This switch prevents unauthorized persons from attempting to operate the machine. When the switch is turned off, the entire electrical system is disconnected and the starting motor cannot be operated.

5. Tachometer. The electric tachometer indicates the engine speed in revolutions per minute.

6. The ammeter. The ammeter indicates the rate of charge or flow of electric current being supplied to the battery by the generator, or the rate of discharge from the battery.

7. Oil pressure gage. The oil pressure gage indicates the pressure of the engine oil, not the amount of oil in the crankcase.

8. Water temperature gage. The temperature gage indicates the temperature of the cooling system of the engine (not the air conditioner).

9. Starting button. Pressing the button, after the key switch is turned on, completes the circuit between the battery and starting motor to crank the engine.

10. Choke control. Pulling the choke out supplies a richer mixture for starting when the engine is cold.

11. Vernier type throttle control. The throttle is equipped with a locking device to hold the control in any desired position.

12. Fuel tank gage. The fuel gage is electrically operated and is connected to the fuel tank sensing unit. The gage indicates the level of gasoline in the tank and will only register after the ignition switch is turned on.

13. Evaporator-condenser water tank gage. Operating similarly to the above, this gage in-

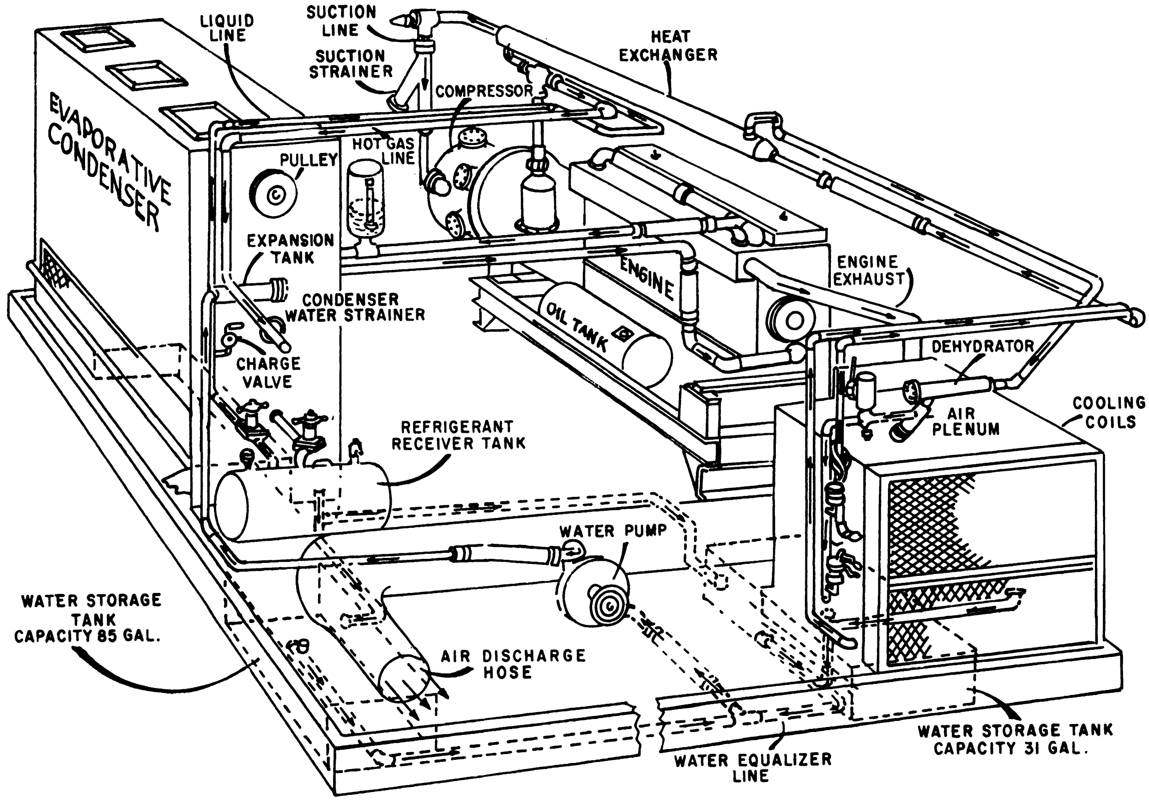


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Figure 6-25.—Air-conditioning unit, functional diagram.

dicates the water level in the evaporative condenser supply tank.

14. Winter switch. This switch is used to operate a solenoid valve in the refrigerant line. In winter, when it is desired to operate the engine without refrigeration, the switch is to be set at the OFF position. For normal operation, however, the switch is to be left ON.

15. Refrigeration gages. These three instruments (reading from left to right when facing the control panel) are: Compressor suction pressure gage, compressor oil pressure gage, and compressor discharge pressure gage.

KOKA 567A

This unit, described as "air conditioner, portable electric," is basically an electric-driven air-conditioning unit mounted on a four-wheel trailer. The unit is intended for use on the flight line to supply cooling air to aircraft during electronic testing or other operational testing.

With a refrigerating capacity of 31.2 tons, the unit uses an 8-cylinder compressor driven by a 60-hp, 440-volt, 3-phase, 60-hertz motor to deliver a maximum of 3,500 cfm of air at a minimum temperature of 45° F. This airflow may be varied by means of a manual damper located in the supply air outlet. Adjustment to requirements can be made by the operator and airflow readings of pressure and volume can be read directly at the instrument panel. An automatic temperature control device will maintain the leaving-air temperature (at the setting of a thermostat with a range of 0° to 120° F, located on the control panel) by varying the volume damper to control airflow. This feature permits maintaining constant air temperature with a slight variation of supply airflow.

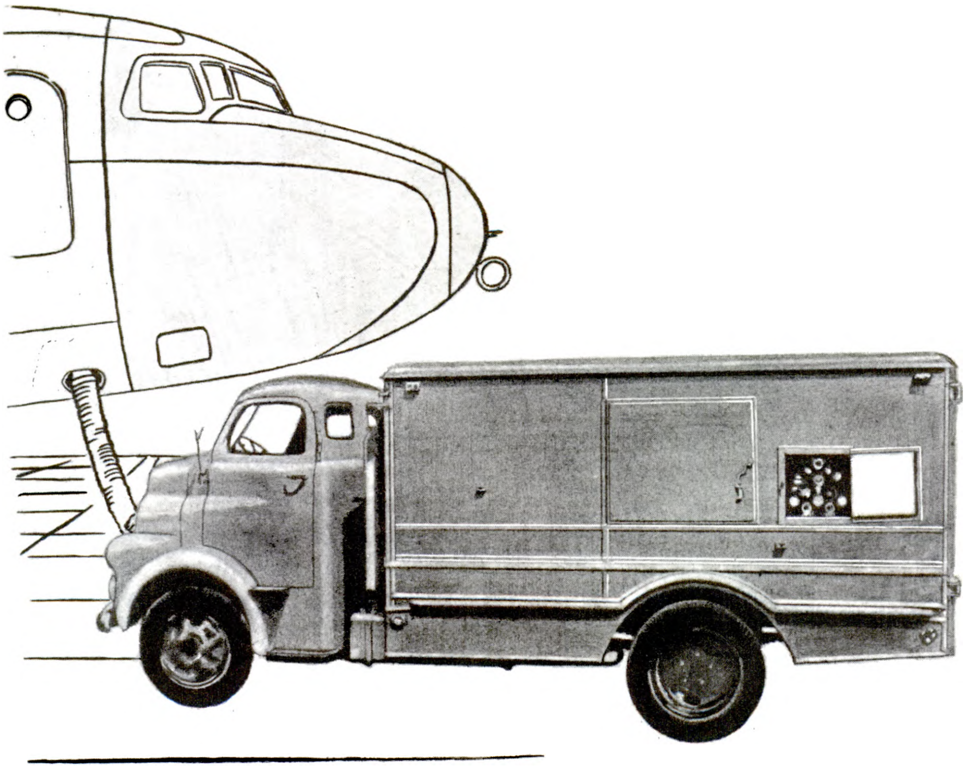

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Figure 6-26.—Air-conditioning truck mounting and control panel.

The refrigeration unit is automatically prevented from operating when the outside ambient air temperature is less than 40° F.

NR-3

The NR-3 is a trailer-mounted, Freon cycle, 120-hp, engine-driven mobile air-conditioning unit. (See fig. 6-27.) This unit is completely selfsustaining and carries enough fuel and water to provide 4 hours of continuous operation. A lunette eye, with a shock control device, is attached to the end of a steerable tow bar and will allow the air conditioner to be towed up to speeds of 40 mph on paved surfaces. A tow bar retainer allows the tow bar to be stowed in the vertical position when not in use. A parking brake provides a means of securing the fully loaded unit on grades up to 35 percent.

This air-conditioning unit supplies cool, moisture-free air to the cabin conditioning and cooling equipment systems during ground checkout and testing of an aircraft's various systems. The unit is capable of delivering 294,000 Btu (24.5 tons gross) of conditioned air. This produces 100 pounds of airflow, at a pressure of 3 pounds per square inch, throughout a range in ambient temperatures from 10° C (50° F) to 43° C (133° F) when measured at sea level. The equipment is designed to operate at altitudes up to 5,000 feet above sea level.

SERVICING UNIT CP 105

The AiResearch CP 105 is a gas turbine-driven power and refrigeration aircraft ground support unit furnished to the Navy in three different configurations. It is used primarily in support of the RA-5C and F-4B aircraft. All three arrangements employ basically the same system, using a small gas turbine to supply electric power and air for refrigeration, main aircraft engine starting, and pilot suit pressurization.

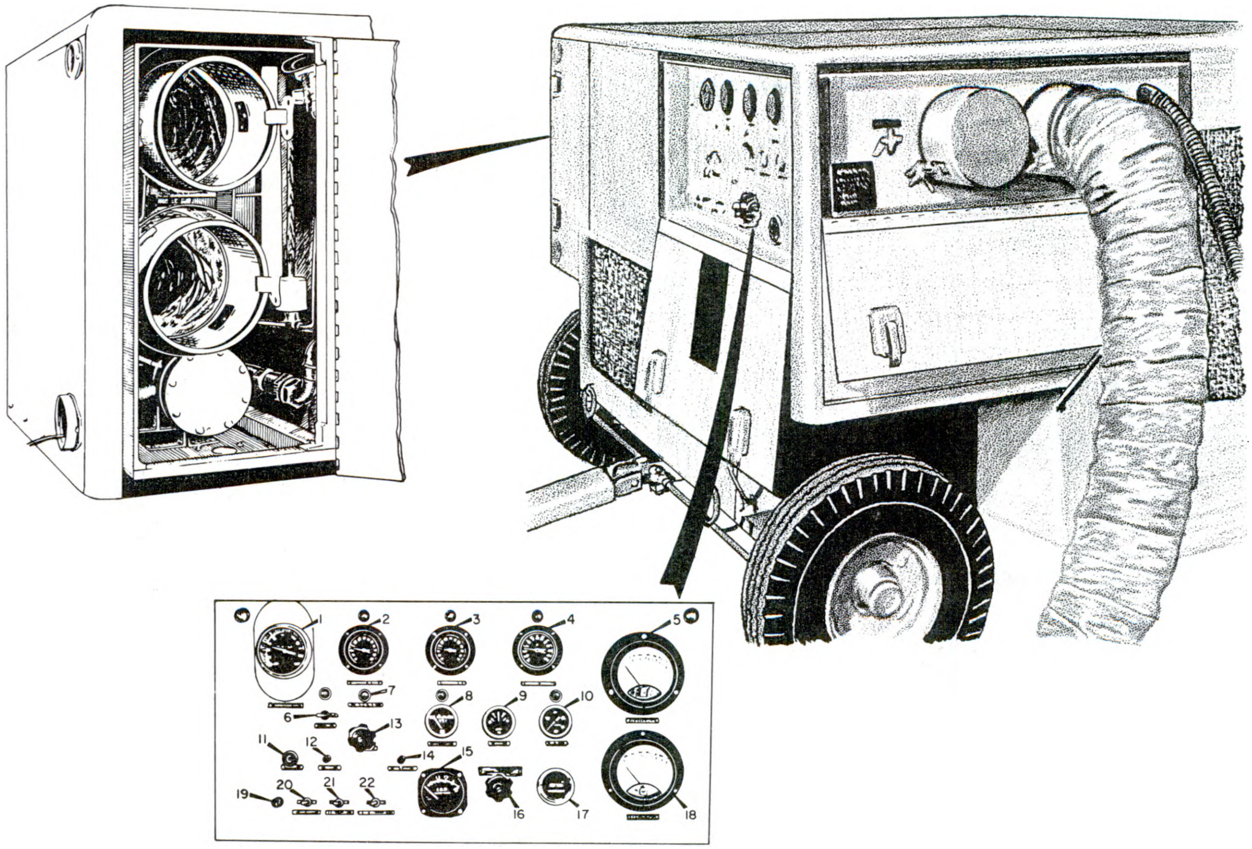

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Figure 6-27.–NR-3 air conditioner.

(NOTE: Electric power is generated by an air-driven turbine.)

The RCPP 105 (one of the three available models) is mounted in a 22-foot long aerodynamic pod for air transportation as an aircraft external store. On the RA-5C, the pod is transported under the wing; on the F-4B, it is carried under the fuselage. A cradle type towable trailer is provided for ground movement of the unit. (See fig. 6-28.)

The RCPT 105 is mounted on a self-propelled, low-silhouette (38 inches from the ground) trailer.

The tractor unit is similar to the RCPT 105 except that the turbine-driven unit is mounted on a diesel tractor.

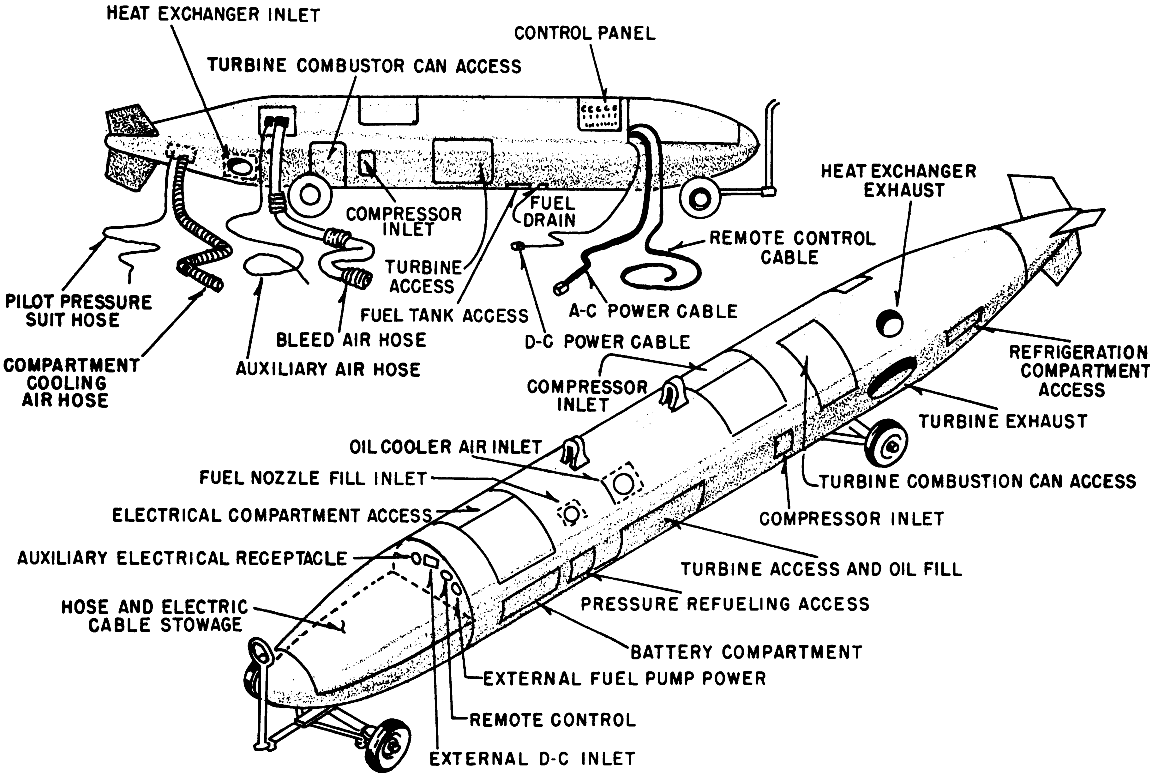

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Figure 6-28.–RCPP 105, showing external connections.

CHAPTER 7

HANDTOOLS

A skilled technician can be identified by the way he handles and cares for his tools and materials. Tools are a costly investment and should be cared for and used to full advantage. There seems to be something about a good tool that helps the average technician turn out better than average work. This fact alone more than justifies the slightly higher cost of quality tools. Even more important is the fact that low quality tools become defective more readily and can result in injury to the user or damage to the equipment undergoing repair.

In the same manner, proper use of quality materials improves the quality of any maintenance task and reduces the possibility of new failures. The primary duties of all maintenance personnel are to become thoroughly familiar with the tools and materials of his trade and be proficient in their care and use.

HANDTOOLS

For purposes of this discussion, the term "handtools" will be used to refer to the small portable or fixed power tools commonly available in electronics maintenance shops or used by electronics maintenance personnel during work on aircraft, as well as those normally classified as nonpowered handtools.

SAFETY, USE, AND CARE OF HANDTOOLS

Carelessness is the greatest menace in any shop. It must come from the man himself; the machine alone cannot inflict injury. Lack of care is the cause of most accidents in electrical and electronics shops today. It should be remembered that all power tools are potentially dangerous. It is unsafe to lean against any that is in motion, or that may be started in motion by anyone else. Treat a machine with businesslike respect and there is no need to fear it. Do not start a machine until its operation has been fully explained by a competent instructor.

Chapter 3 of this manual contains some information concerning safety precautions and practices involving machinery and tools; that material should be reviewed frequently. Other excellent sources of information regarding handtools and their use and care are the Rate Training Manuals Airman, NavPers 10307-B, and Basic Handtools, NavPers 10085-A. Since these manuals are basic to all aviation ratings, the material covered in them is not duplicated in this discussion; review of that material should be accomplished before proceeding with this manual.

The following two basic safety precautions may be used to summarize this idea, and they cannot be emphasized too strongly:

1. Use the proper tool for its own specific function, and use it in the proper manner.
2. Maintain all tools in proper working order and in a safe condition. Sharpen or replace dulled cutting tools, replace broken or defective tools, and protect tools from damage while in use or in storage.

When performing any function requiring the use of tools and/or materials, arrange them so that they are easily accessible but are not in a position to interfere with the work. This arrangement increases efficiency as well as safety.

Tools should be cleaned and inspected after the job has been completed. Return all tools to their proper storage place. If a tool becomes worn, damaged, or broken, report it to the senior member of the shop so that proper steps may be taken for replacement or repair.

GENERAL TOOLS

Although the previously mentioned basic courses provide many details regarding the common general tools, a few additional comments are of importance to the avionics maintenance technician.

Never use a center punch on extremely hard metals or to remove bolts by force; to do so will dull the point. Never use a pin punch as a starting punch–a hard blow may cause the slim shank to break. Always use the largest starting and pin punches that will fit the hole. When using punches, do not strike a glancing blow; the punch may break, and broken pin punches are difficult to remove.

Do not hammer on a screwdriver. If an obstruction is in the slot, apply a driving force with the heel of the hand or remove the obstruction with a file. Never use a screwdriver as a pry bar, lever, or chisel. Do not use pliers or wrenches on a screwdriver to increase torque.

When using a grinding wheel, insure that the guard is in place. If it is necessary to use the wheel with the guard removed, stand to one side to avoid flying particles of emery or metal. Use safety goggles when grinding screwdriver blades or other metal objects. Nonferrous metals should never be ground with ordinary grinding wheels due to the danger of the wheel becoming loaded with the material and possibly exploding. Use the rest stand when possible, but insure that the rest is close to the grinding wheel.

When drilling, never use the hand to hold the work being drilled. Use a vise or a clamp. The same idea applies to work being soldered, filed, or sawed.

Know Your Screwdrivers

Using a Reed and Prince screwdriver for working on Phillips screws (or vice versa) can result in a ruined tool or a ruined screwhead, making it difficult to remove the screw. Because of the difference in design of the two screws, the screwdrivers should not be used interchangeably. In general, Reed and Prince screws are used for airframe structural applications, while Phillips screws are found most often in component assemblies.

Figure 7-1 shows the differences between types. The Phillips screwdriver has about 30-degree flukes and a blunt end, while the Reed and Prince has 45-degree flukes and a sharper, pointed end. The Phillips screw has beveled walls between the slots; the Reed and Prince, straight, pointed walls. In addition, the Phillips screw is not as deep as the Reed and Prince.

Ways to identify the right screwdriver are as follows:

1. If it tends to stand up unassisted when the point is put in the head of a vertical screw, it is probably the proper one.
2. The outline of the end of a Reed and Prince screwdriver is approximately a right angle, as seen in the illustration.
3. Know the descriptions of both types. Using the right tool saves time and trouble, and is good maintenance practice.

Soldering Iron

All high quality irons operate in the temperature range of 500° to 600° F. Even the little 25-watt midget irons produce this temperature. The important difference in iron sizes is not temperature, but thermal inertia (the capacity of the iron to generate and maintain a satisfactory soldering temperature while giving up heat to the joint to be soldered).

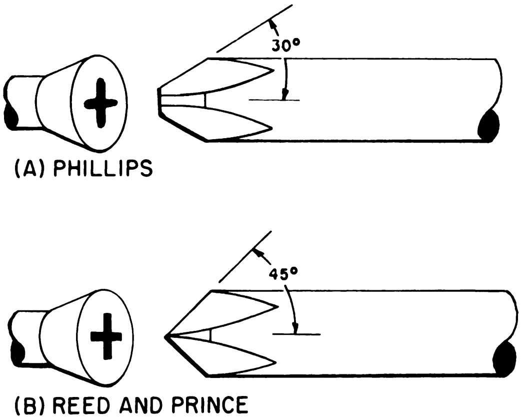

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Figure 7-1.–Matching cross-slot screws and drivers.

Although it is not practical to try to solder a heavy metal box with the 25-watt iron, that iron is quite suitable for replacing a half-watt resistor in a printed circuit. An iron with a rating as large as 150 watts would be satisfactory for. use on a printed circuit, provided that suitable soldering techniques are used. One advantage of using a small iron for small work is that it is light and easy to handle and has a small tip which is easily inserted into close places. Also, even though its temperature is high, it does not have the capacity to transfer large quantities of heat.

Some irons have built-in thermostats. Others are provided with thermostatically controlled stands. These devices control the temperature of the soldering iron, but are a source of trouble. A well-designed iron is self-regulating by virture of the fact that the resistance of its element increases with rising temperature, thus limiting the flow of current. For critical work, it is convenient to have a variable transformer for fine adjustment of heat; but for general-purpose work, no temperature regulation is needed.

Soldering Gun

The soldering gun has gained great popularity in recent years because it heats and cools rapidly. It is especially well adapted to maintenance and troubleshooting work where only a small part of the technician's time is spent actually soldering. A soldering iron, if kept hot constantly, oxidizes rapidly and is therefore difficult to keep clean.

A transformer in the gun supplies approximately 1 volt at high current to a loop of copper which acts as the tip. It heats to soldering temperature in 3 to 5 seconds, but may overheat to the point of incandescence if left on over 30 seconds. The gun is operated with a finger switch so that the gun heats only while the switch is depressed.

Since the gun normally operates only for short periods at a time, it is comparatively easy to keep clean and well tinned; thus, little oxidation is allowed to form. However, the tip is made of pure copper, and is susceptible to pitting which results from the dissolving action of the solder.

Tinning of the work is always desirable unless it has already been done. The gun or iron should always be kept tinned in order to permit proper heat transfer to the work to be soldered. Tinning also provides adequate control of the heat to prevent thermal spillover to nearby materials. Tinning of the tip of a gun may be somewhat more difficult than tinning the tip of an iron. Maintaining the proper tinning on either type, however, may be made easier by tinning with silver solder. The temperature at which the bond is formed between the copper tip and the silver solder is considerably higher than with lead-tin solder. This tends to decrease the pitting action of the solder on the copper tip.

Pitting of the tip indicates the need for retinning, after first filing away a portion of the tip. Retinning too often results in using up the tip too fast.

Overheating can easily occur when using the gun to solder delicate wiring or printed circuits. With practice, however, the heat can be accurately controlled by pulsing the gun on and off with its trigger. For most jobs, even the LOW position of the trigger overheats the gun after 10 seconds; the HIGH position is used only for fast heating and for soldering heavy connections.

Heating and cooling cycles tend to loosen the nuts or screws which retain the replaceable tips on soldering irons or guns. When the nut on a gun is loosened, the resistance of the tip connection increases, and the temperature of the connection is increased. Continued loosening may eventually cause on open circuit. Therefore, the nut should be tightened periodically.

Soldering guns, as well as soldering irons, may be used on the 400-hertz. Normally results in a lowered temperature (at the expense of an increased time), but satisfactory soldering temperatures may be obtained with no damage to the tools.

Resistance Soldering

A time-controlled resistance soldering set (fig. 7-2) is now available through normal supply channels. The set consists of a transformer that supplies 3 or 6 volts at high current to stainless steel or carbon tips. The transformer is turned ON by a foot switch and OFF by an electronic timer. The timer can be

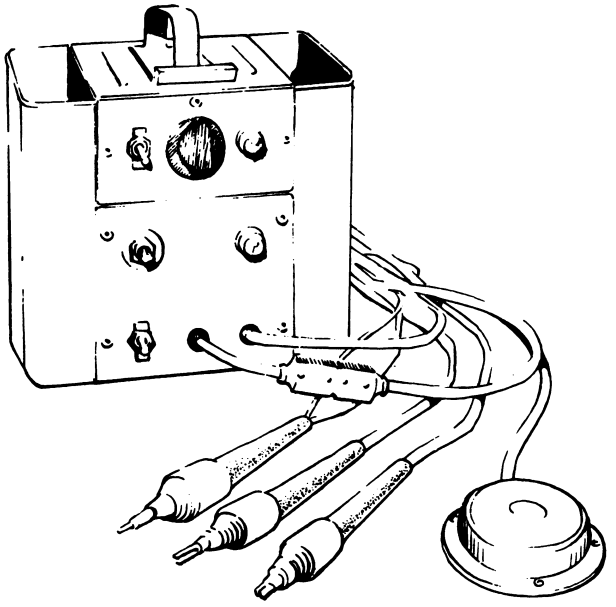

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Figure 7-2.—Resistance soldering unit.

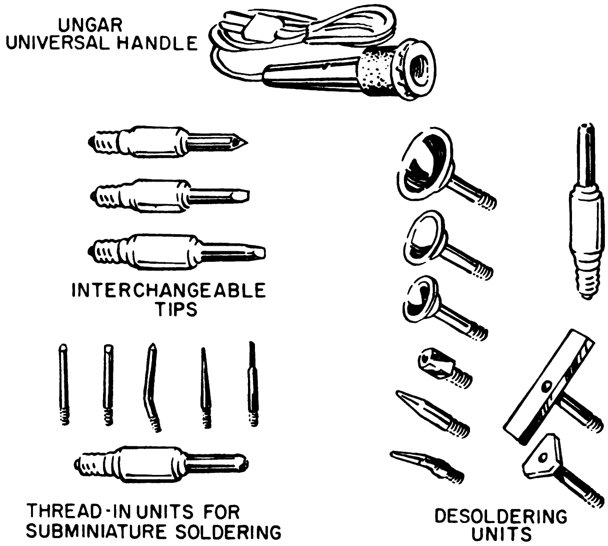

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Figure 7-3.—Pencil iron kit with special tips.

adjusted for as long as 3 seconds soldering time. This set is especially useful for soldering cables to MS/AN plugs and similar connectors—even the smallest types available.

In use, the double-tip probes of the soldering unit are adjusted to straddle the connector cup to be soldered. One pulse of current heats it for tinning and, after the wire is inserted, a second pulse of current completes the job. Since the soldering tips are hot only during the brief period of actual soldering, burning of wire insulation and melting of connector inserts are greatly minimized.

The greatest difficulty with this device is keeping the probe tips free of rosin and corrosion. A cleaning block is mounted on the transformer case for this purpose. Some technicians prefer fine sandpaper for cleaning the double tips.

CAUTION: Do not use steel wool. It is dangerous when used around electronic equipment.

Pencil Iron and Special Tips

An almost indispensable item is the pencil type soldering iron with an assortment of tips (fig. 7-3). Miniature soldering irons, with wattage ratings of less than 40 watts are easy to use and are recommended. In an emergency, larger irons can be converted and used on subminiature equipment as described later in this section.

One type of iron is equipped with several different tips that range from one-fourth to one-half inch in size (diameter) and are of various shapes. This feature makes it adaptable to a variety of jobs. Unlike most tips which are held in place by setscrews, these tips have threads and screw into the barrel. This feature provides excellent contact with the heating element, thus improving heat transfer efficiency. A pad of "antiseize" compound is supplied with each iron. This compound is applied to the threads each time a tip is installed in the iron, thereby enabling the tip to be easily removed when another is to be inserted.

A special feature of this iron is the soldering pot that screws in like a tip and holds about a thimbleful of solder. It is useful for tinning the ends of large numbers of wires.

The interchangeable tips are of various sizes and shapes for specific applications.

Extra tips may be obtained and shaped to serve special purposes. The thread-in units are useful in soldering subminiature items. The desoldering units are specifically designed for performing special and individual functions.

Another advantage of the pencil soldering iron is its possible use as an improvised light source for inspections. Simply remove the soldering tip and insert a 120-volt, 6-watt, type 6S6, candelabra screwbase lamp bulb into the socket.

If leads, tabs, or small wires are bent against a board or terminal, slotted tips may be used to simultaneously melt the solder and straighten the leads.

A hollow tip, which fits over a pin terminal, may be used to desolder and resolder wiring at cables or feed-through terminals.

Many microminiature components have multiple connections, all of which must be desoldered to permit removal of the component in one operation. These connections may be desoldered individually by heating each connection and brushing away the solder. With this method, particular care must be taken to insure that loose solder does not stick to other parts or become lodged where it may cause a short circuit. A more efficient method is to use the specially shaped desoldering units (fig. 7-3). Select the proper size and shape tip that will contact all terminals to be desoldered—and nothing else. Do not permit the tip to remain in contact with the terminals too long at one time.

If no suitable tip is available for a particular operation, an improvised tip may be made. Wrap a length of copper wire around one of the regular tips and bend the wire into the proper shape for the purpose. Insure that the improvised tip contacts all connections and nothing else. This method also serves to reduce tip heat when a larger iron must be used on miniature components. (See fig. 7-4.)

In connection with the discussion of soldering tools and devices, the selection of solder and flux is also critical. A small diameter rosin core solder with a high tin-lead ratio is normally preferred (63/37 or 60/40). Normally the higher the lead content, the higher the melting point. In miniature circuits heat is critical, and the higher tin-to-lead ratio requires less heat to make a strong and lasting joint. An exception is in soldering a silver plated or solid silver item. For this application the solder must contain 2 to 3 percent silver to prevent chemical action which could destroy the component.

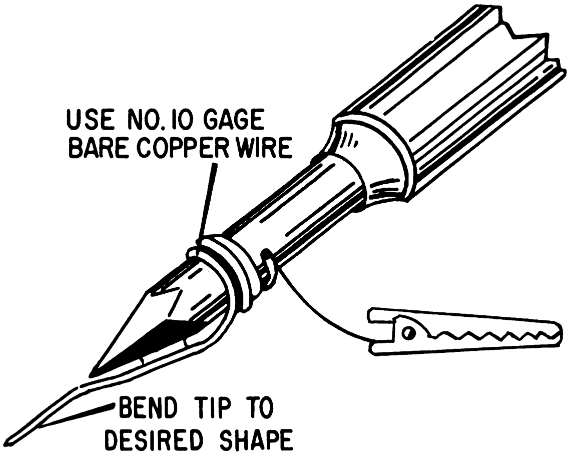

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Figure 7-4.—Improvised tip to reduce heat.

Any flux used must be noncorrosive and nonconductive, to prevent corrosion, shorts, and electrical leakage.

Soldering Aids

Several devices other than the soldering iron and its tips are required in soldering miniature circuits.

Some type of thermal shunt is essential in all soldering operations which involve heat-sensitive components. Pliers, tweezers, or hemostats may be used for some applications, but their effectiveness is limited. A superior heat shunt is shown in figure 7-5. Proper use of the heat shunt permits soldering the leads of component parts without overheating the part itself.

For maximum effectiveness, any protective coating should be removed before applying the heat shunt. The shunt should be attached carefully to prevent damage to the leads, terminals, or component parts. The shunt should be clipped to the lead, between the joint and the part being protected. As the joint is heated, the shunt absorbs the excess heat before it can reach the part and cause damage.

A small piece of beeswax may be placed between the protected unit and the heat shunt. When the beeswax begins to melt, the temperature limit has been reached. The heat source should be removed immediately, but the shunt should be left in place.

Premature removal of the heat shunt permits the unrestricted flow of heat from the melted solder into the component. The shunt should be allowed to remain in place until it cools to room temperature. A clip-on type shunt is preferred because it requires positive action to remove the shunt, but does not require that the technician maintain pressure to hold it in place.

Another invaluable soldering aid is the "solder sucker" syringe. One type is shown in figure 7-6. Its purpose is to "suck up" excess solder (and incidentally the excess heat) from a joint. The only requirements of an efficient solder sucker are a controllable source of vacuum (squeeze bulb), a solder receiver, and a tip. The tip must be able to withstand the heat of molten solder. Teflon is ideal, but is difficult to acquire through Navy supply channels. A silicon rubber-covered Fiberglas sleeving with an inner diameter of 0.162 inches (FSN 9N5970-285-0488) and the bulb from a medicine dropper makes a suitable syringe. (The glass or plastic tip of the medicine dropper cannot withstand the heat.)

SOLDER

Two types of solder are available—the tin-lead alloy known as soft solder and the so-called hard or silver solder. Soft solder alloys permit the use of lower soldering temperatures and are therefore recommended for electronic applications. Where a joint of greater strength is required, silver solder is employed.

Most solder alloys do not liquefy immediately as the temperature is increased. Ordinarily they change from the solid state to a plastic semiliquid, and finally become completely liquid. Most tin-lead solders enter the plastic state at 358° F and become wholly liquid at various temperatures, dependent upon the individual composition. A combination of 63 percent tin and 37 percent lead has the lowest melting point (361° F) for the tin-lead group. However, since it changes from solid to liquid without an intervening plastic state, it is susceptible to fracture from slight vibration while cooling.

(Solder is commonly referred to as 70/30, 60/40, etc. This is the tin-lead content.)

FLUXES

All common metals are covered with a nonmetallic film, usually an oxide of the material, which prevents them from making the intimate contact so necessary for a good electrical connection. The purpose of a flux is to remove the oxide from the surfaces to be soldered, not to clean them. Flux cannot replace good cleaning methods in preparing surfaces for soldering. Without a clean, inti-

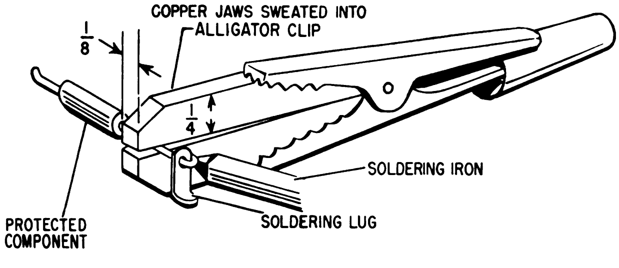

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Figure 7-5.—Heat shunt.

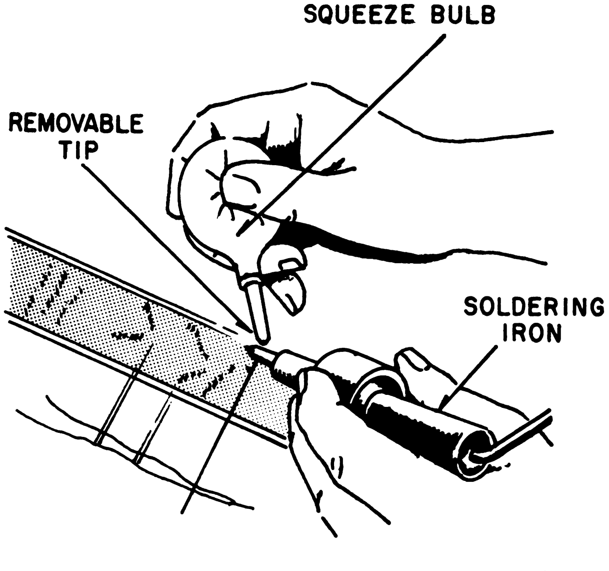

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Figure 7-6.—Solder sucker.

mate contact, poor soldering techniques may result in a mechanically weak, high resistance joint—a so-called rosin joint in the case of rosin-base flux.

Solder fluxes may be divided into three general groups—rosin, organic, and chloride (sometimes called acid). The residue from the rosin-base fluxes is noncorrosive and electrically nonconductive, making them highly acceptable for use in military electronic equipment. The organic and chloride types are seldom used (sometimes even prohibited) because of their corrosiveness. Actually, only rosin-base flux is recommended for electronic applications.

ROSIN flux is actually very active when melted by heat. However, after the normal heat of the soldering operation is removed, the dry solid residue is noncorrosive and electrically nonconductive. Activated or intensified rosin-alcohol fluxes are permitted by MIL-S-6872 if they are noncorrosive. (For details, consult this specification.)

ORGANIC fluxes consist of mild organic acids and bases. These fluxes are almost as active as the organic salts, but their period of activity is brief due to their susceptibility to thermal decomposition. This limits corrosion and therefore may be used in applications where the soldered assembly lends itself to residue removal.

CHLORIDE type fluxes are not recommended for electronic applications.

SPECIAL TOOLS

A wide variety of special tools is required to maintain the modern aircraft of today's Navy. These tools are furnished by the manufacturers of the aircraft, engines, and related equipment.

Proper use of special tools greatly reduces the man-hours required for maintenance work.

These tools are listed in allowance lists published by the Naval Air Systems Command, and their use is explained in the Maintenance Instructions Manual or the Service Instruction Manual covering the particular aircraft, engine, or piece of equipment for which they were designed. An example of a special tool that is required for special maintenance of equipment, is the cable assembly connector wrench. This wrench is used to remove the sonar dome from the electrical special purpose cable assembly. (See fig. 7-7.)

NONMAGNETIC TOOLS

Tools made of nonmagnetic materials are available through normal supply channels. They are used for performing specific maintenance functions on certain classes of equipment or components—such as maintaining the detecting heads of MAD equipment. These tools, normally made of beryllium-copper, are used because steel tools may become magnetized through normal use.

Restricting the use of the nonmagnetic tools to the purpose for which they are intended will increase their value to the technician. Use of these tools for general maintenance would allow them to transfer metal or other foreign particles into electronic equipment. The gears and bearings of the detecting head are easily fouled by small particles of dust or metal. In addition to mechanical fouling, the introduction of metal particles that are magnetized would cause magnetic noise in the detecting head.

Nonmagnetic tools should also be used in tuning RF circuits which are susceptible to frequency change resulting from the introduction of new magnetic fields (or the distortion of the existing magnetic fields). Many slug-tuned IF circuits involve this potential trouble.

Good general maintenance practice involves wiping the tools before use and again after use. This is especially advisable in the case of nonmagnetic tools. A lint-free cloth dampened with a suitable cleaning solvent may be used for this purpose.

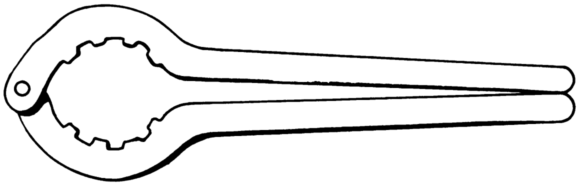

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Figure 7-7.—Cable assembly connector wrench.

Nonmagnetic metals are usually softer than steel, so use of these tools for general maintenance could also damage the tools.

INSULATED TOOLS

Safety considerations require use of insulated tools whenever the danger of electrical shock or short circuit exists. Many types of tools are available in insulated form directly through supply channels at little or no additional cost. These tools should be obtained and used whenever available. However, many types of insulated tools are not readily available (or are available only at considerable added expense). If essential, these tools should be procured or conventional tools may be modified. Insulated sleeving may be put on the handles of pliers and wrenches and on the shanks of screwdrivers. Tools modified in this manner should be used only for low voltage circuits because of the limitations of the insulating materials. For higher voltage uses, special insulating handles are available for many of the common types of tools.

In some instances, it is necessary to use tools which are made of insulating material, rather than merely having an insulating handle. In these instances, the tools should be requisitioned through normal supply channels, if possible. If they are not available through normal supply channels, they may be purchased on the open market.

TORQUE WRENCHES

There are times when, for engineering reasons, a definite pressure must be applied to a nut. In such cases a torque wrench must be used. The torque wrench is a precision tool consisting of a torque-indicating unit and appropriate adapter or attachments. It is used to measure the amount of turning or twisting force applied to a nut, bolt, or screw.

The three most commonly used torque wrenches are the deflecting beam, dial indicating, and micrometer setting types (fig. 7-8.) When using the Deflecting Beam and the Dial Indicating torque wrenches, the torque is read visually on a dial or scale mounted on the handle of the wrench.

To use the micrometer setting type, unlock the grip and adjust the handle to the desired setting on the micrometer type scale, then relock the grip. Install the required socket or adapter to the square drive of the handle. Place the wrench assembly on the nut or bolt and pull in the desired direction with a smooth, steady motion. (A fast or jerky motion will result in an improperly torqued unit.) When the torque applied reaches the torque value which is indicated on the handle setting, the handle will automatically release or "break" and move freely for a short distance. The release and free travel is easily felt, so there is no doubt the torquing process is complete.

To assure getting the correct amount of torque on the fasteners, all torque handles must be tested at least once a month or more often if usage indicates it is necessary.

The following precautions should be observed when using torque wrenches:

1. Do not use the torque wrench as a hammer.
2. When using the micrometer setting type, do not move the setting handle below the lowest torque setting. However, it should be placed at its lowest setting prior to returning to storage.
3. Do not use the torque wrench to apply greater amounts of torque than its rated capacity.
4. Do not use the torque wrench to break loose bolts which have been previously tightened.
5. Never store a torque wrench in a toolbox or in an area where it may be damaged.

Torque Information

The torque table (table 7-1) may be used as a guide in tightening nuts, bolts, and screws whenever specific torque values are not called out in maintenance procedures. Using the proper torque allows the structure to develop its designed strength and greatly reduces the possibility of failure due to fatigue.

Threads must be free from grease or oil. Lubrication changes the torque value and will result in overtorquing.

When castellated nuts are used, they should be tightened to the lower torque limit; then continue tightening until cotter pin hole is

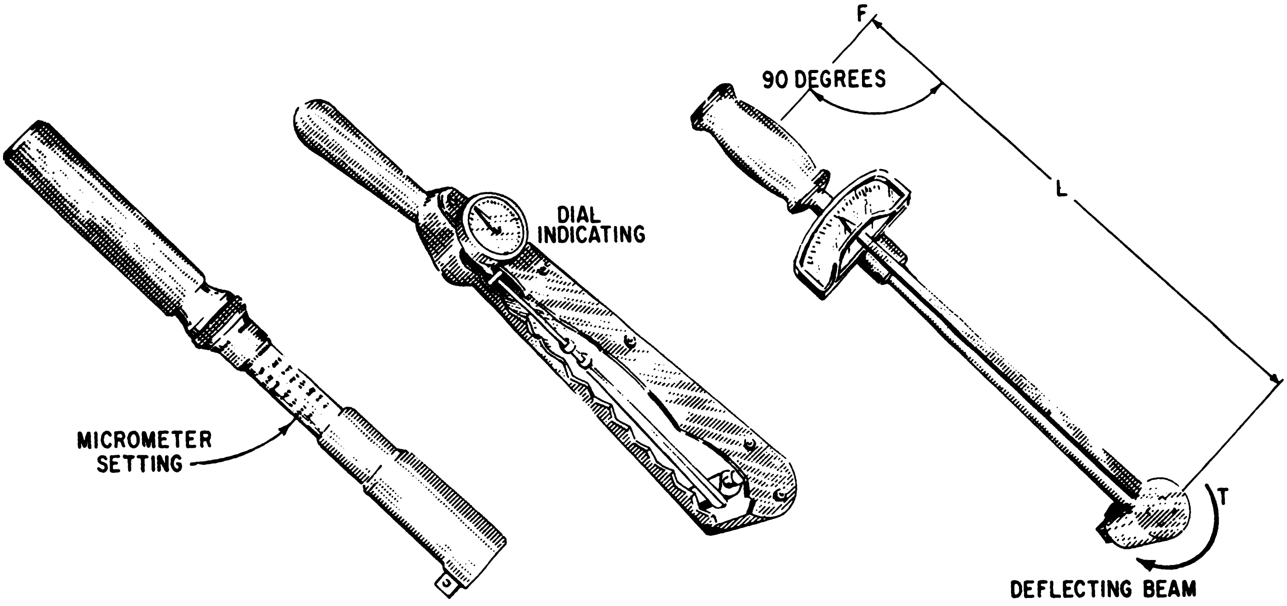

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Figure 7-8.—Torque wrenches.

alined with slots in nut. Do not back off nut to aline hole.

When it is necessary to tighten from the bolthead, use the high side of the torque range. If necessary, the maximum allowable tightening torque may be used.

When corrosion-resistant steel bolts are used, they should be lubricated with an antiseize compound. Corrosion-resistant steel bolts and nuts must be used together. Use shear nut torque values when tightening these bolts.

RELAY TOOLS

Two of the more common handtools used to repair relays are the burnishing tool and the point bender. The use of these two items is discussed in the following paragraphs.

Burnishing Tool

Many relays have been damaged or ruined by the use of sandpaper or emery cloth to clean the contact points. Use of these abrasives causes bending of the contacts; and attempts to straighten them with long nosed pliers cause further damage, eventually requiring replacement of the relays. This can be avoided by using a burnishing tool to clean dirty contact points.

Figure 7-9 illustrates a burnishing tool being used on a relay.

Two common types of burnishing tools are stocked in supply activities and may be obtained through normal supply channels. These two common burnishing tools are 2 33/64 inches and 5 inches in length.

Be sure to clean the tool thoroughly with alcohol and do not touch the tool surface with your fingers prior to use.

Burned and pitted contacts cannot be repaired by burnishing. Relays having trouble this serious should be replaced.

Point Bender

Another handy tool that is often found in a toolbox is a point bender. The point bender (fig. 7-10) is used to straighten bent relay contacts. This bender can be fabricated locally from 0.125-inch diameter rod stock according to the dimensions in the figure.

Table 7-1.—Torque values in inch-pounds.

Wrench size (in.)	Standard nuts, bolts, and screws		
	Bolt, stud, or screw size	Tension type nuts AN310 and AN365	Shear type nuts AN320 and AN364
1/4	4-48	4-5.5	2.5-3.5
5/16	6-40	7.5-11	4.5-6.5
11/32	8-36	12-15	7-9
3/8	10-32	20-25	12-15
7/16	1/4-28	50-70	30-40
1/2	5/16-24	100-140	60-85
9/16	3/8-24	160-190	95-110
5/8	7/16-20	450-500	270-300
3/4	1/2-20	480-690	290-410
7/8	9/16-18	800-1,000	480-600
15/16	5/8-18	1,100-1,300	660-780
1 1/16	3/4-16	2,300-2,500	1,300-1,500
1 1/4	7/8-14	2,500-3,000	1,500-1,800
1 7/16	1-14	3,700-5,500	2,200-3,300

NOTE: To convert to foot-pounds, divide inch-pounds by 12

WIRE AND CABLE TOOLS

An innovation in electrical connectors is the taper pin electrical connector for aircraft. The taper pin works on the principle of driving a taper wedge into a tapered hole and depending on friction to retain the pin in the hole. The taper pin connector makes a very good electrical and mechanical connection because of the high metal to metal contact pressure developed during the driving action of the insertion tool. Taper pins permit circuit changes to be quickly and easily performed without a soldering iron. Tests show that vibration and corrosion, over a period of time, improve the electrical continuity and increase the mechanical pulling force required to remove a taper pin. Another advantage of taper pins is the accessibility of test points for voltage and circuit continuity checks.

Insertion and Removal

A special tool, shown in figure 7-11, is used to properly insert the taper pin into the terminal block socket. The insertion tool has a calibrated

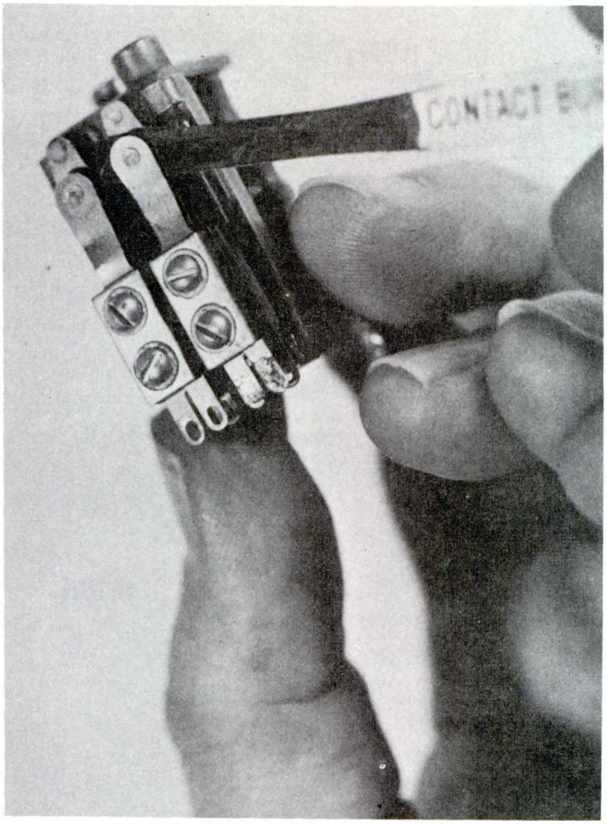

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Figure 7-9.—Burnishing tool.

driving spring, a calibrated pull test spring, a taper pin captive key, and a taper pin removal feature.

The driving spring adjusts to apply the proper driving impact to the pin. The pull test spring adjusts to apply the correct pull force on the pin to check for proper pin insertion. The captive key insures that each taper pin has a 100 percent pull test before the tool is disengaged from the pin. The removal lever is rotated to remove the taper pin from the terminal block socket.

In order to maintain the reliability of the system, it is imperative that the taper pin be properly inserted into the terminal block sockets. Pushing the pins into the sockets with the fingers or pliers will not make them stay—they must be driven in with the insertion tool. The tool must be calibrated to insure that the proper pressures are used. When inserting the taper pins, the insertion tool must be held at right angles to the terminal block, and pushed straight toward the terminal block without twisting the tool. The pins are very sensitive to twists, which could cause a faulty connection or a broken pin. Bent or broken pins should always be replaced. However, if correct installation procedures are followed, a taper pin may be installed and removed as many as 25 times before a replacement is necessary. A properly installed taper pin will pass the pull test of the insertion tool.

Three different sizes of taper pins are used to terminate wires from size 16 through size 22. The sizes are identified by color coding of the insulating sleeves. A crimping tool is used to attach the taper pin to the wire. This taper pin crimping tool is similar to other types of wire terminal crimping tools, such as those discussed later in this chapter.

Stripper

Nearly all wire and cable used as electrical conductors are covered with some type of insulation. In order to make electrical

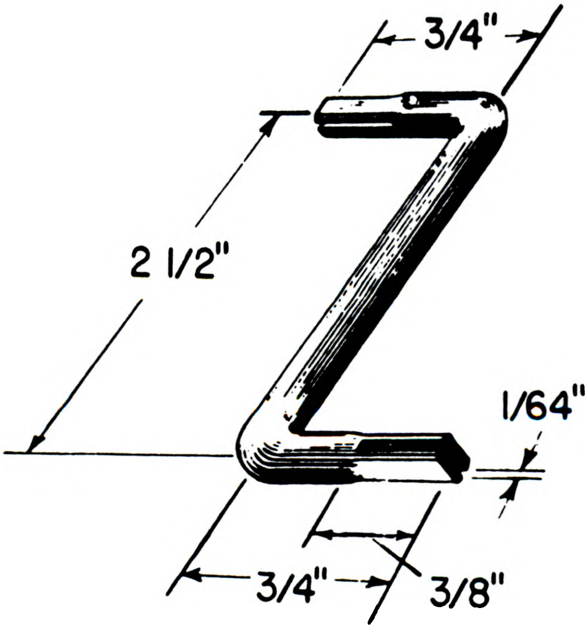

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Figure 7-10.—Point bender.

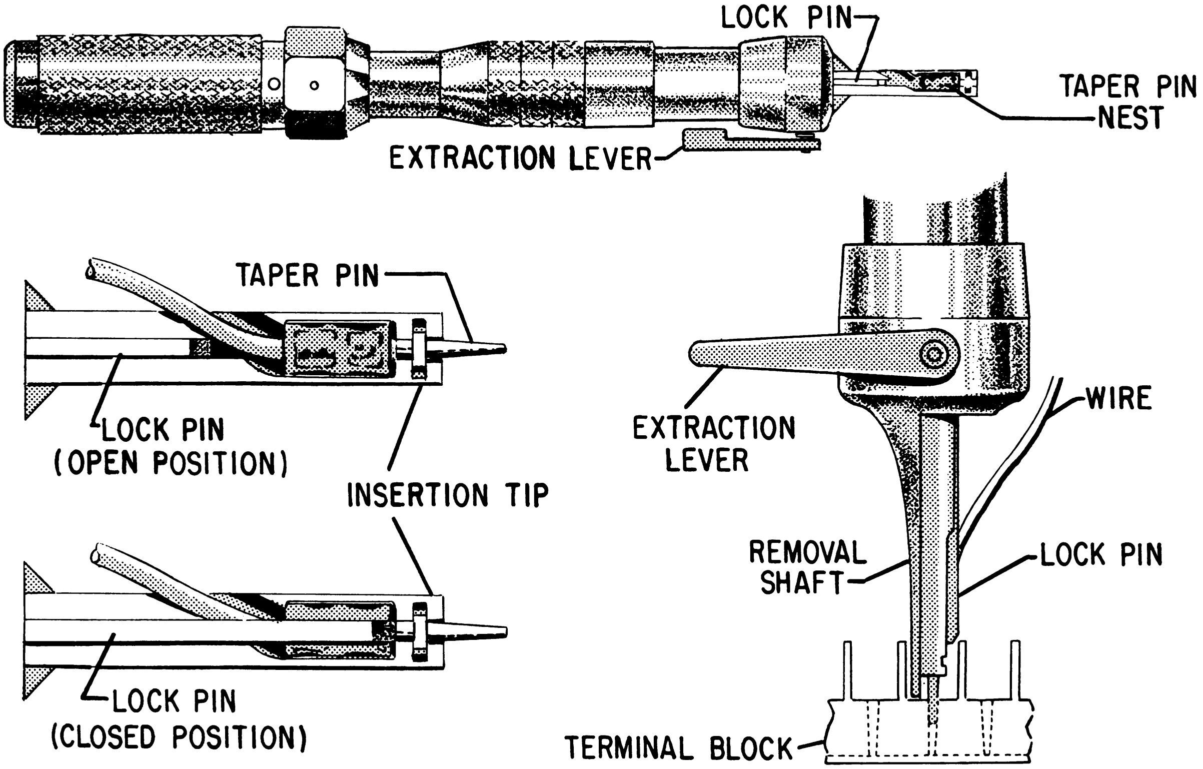

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Figure 7-11.–Taper pin insertion and removal tool.

connections with the wire, a part of this insulation must be removed, leaving the end of the wire bare. To facilitate the removal of this insulation, use a wire and cable stripping tool similar to the one shown in figure 7-12.

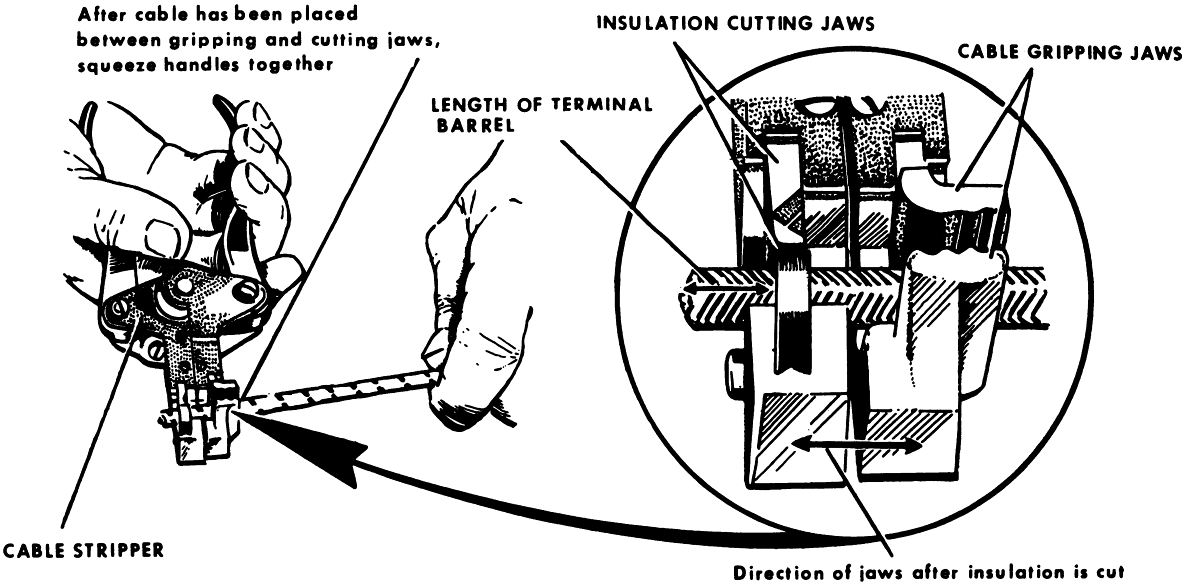
Although several variations of this basic tool are available, the most efficient and effective is the type illustrated. Its operation is extremely simple–insert the end of the wire in the proper direction to the depth to be stripped, position the wire so that it rests in the proper groove for that size wire, and squeeze. The tool functions in three steps as follows:

1. The cable gripping jaws close, clamping the insulated wire firmly in place. The wire must be inserted so that the jaws clamp the main section of the wire rather than the end to be stripped.

2. The insulation cutting jaws close, cutting the insulation. If the wire is not inserted in a groove, the conductor will also be cut. If the wire is positioned into too small a groove, some of the strands will be severed. If the groove is too large, the insulation will not be completely severed. Inserted properly into the correct groove, the insulation will be cut neatly and completely, and the wire will not be damaged.

3. The two sets of jaws separate, removing the clipped insulation from the end of the wire.

If cable and wire strippers of this type are not available, notches may be cut in the jaws of diagonal pliers or pocket fingernail clippers, using jeweler's files. Care must be taken to file the grooves into the proper positions in opposing jaws, and the size of the groove must be appropriate for the size wire on which it is to be used. When properly modified, these tools will perform satisfactorily if the more desirable stripper is not available.


After cable has been placed between gripping and cutting jaws, squeeze handles together
INSULATION CUTTING JAWS
CABLE GRIPPING JAWS
LENGTH OF TERMINAL BARREL
CABLE STRIPPER
Direction of jaws after insulation is cut

AE.37

Figure 7-12.–Wire and cable stripper.

CRIMPING TOOLS

Type MS 25037-1

The standard tool MS 25037-1, issued for crimping solderless terminals, is for use with standard insulated copper terminal lugs manufactured according to MS 25036. The standard tool employs a double jaw to hold the terminal lug or splice. One side of the jaw applies crimping action to fasten the terminal to the bare wire when the terminal is inserted, as shown at the left in figure 7-13. When the tool is used correctly, a deep crimp is placed in the B area of terminal lugs and splices, as shown in diagrams on the right of the figure. A shallow crimp is applied to the portion of the terminal or splice which extends over the insulation of the wire, as indicated by the A area in the diagrams. This clamping action is provided by a recessed portion in the other side of the divided jaw. A guard, which should be in the position shown when crimping terminals, aids in proper positioning of the terminal. However, the guard must be moved out of the way when the tool is used for crimping splices.

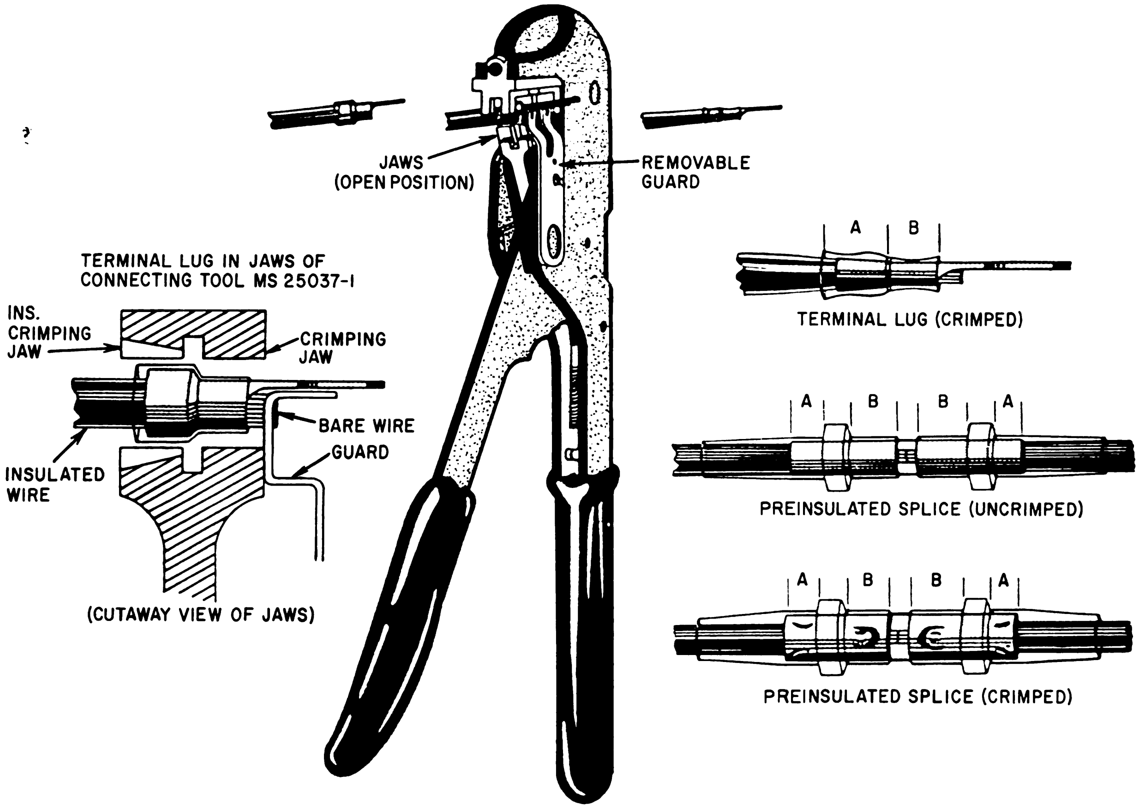
Without the guard, the tool may be used incorrectly; for example, the terminal might be inserted from the wrong side of the tool. The result is that the deep crimp is placed in the A area of the terminal or splice and, although the wire may be held securely in place, the connection is poor. Common sense indicates that the deep crimp must clamp the metal of the terminal to the bare metal of the wire in order to provide a good electrical and mechanical connection.

The MS 25037-1 tool requires occasional checking. A No. 36 (0.106) drill rod should not be able to enter the smaller (red or blue) nest when the tool is fully closed. If it does enter, have the tool repaired.

Instruction in proper crimping procedure should be furnished to all who need to make solderless terminal connections. Handbook of Installation Practices for Aircraft Electric and Electronic Wiring, NavAer 01-1A-505, contains detailed procedures for using many solderless connector tools.

Type MS 3191-3

This tool is the latest standard crimping tool designed specifically for use with type MS 3191 contacts for electrical connectors.



AE.38

Figure 7-13.—Crimping tool MS 25037-1.

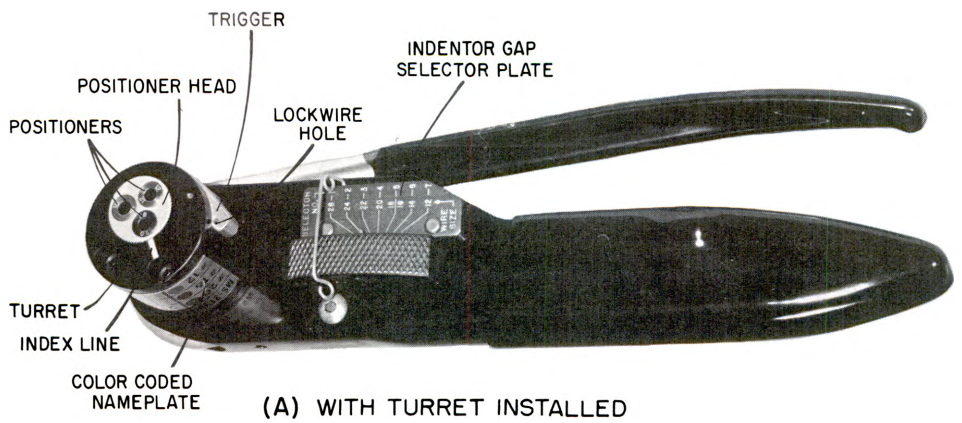
It features interchangeable heads to accommodate various size terminals. It may be used with the turret (fig. 7-14 (A)) for normal use, or without the turret (fig. 7-14 (B)) for eyeball crimping.

Before using the tool, the correct selection must be made on the positioner head and also on the indentor gap selector plate. To release the turret for indexing, press the trigger and the spring-loaded turret snaps out to its indexing position. Select the desired position from the color-coded nameplate and rotate the turret to aline the selected positioner with the index. Depress the turret until flush, and the turret will automatically lock into place. To prevent further indexing, insert lockwire through the hole provided in the trigger.

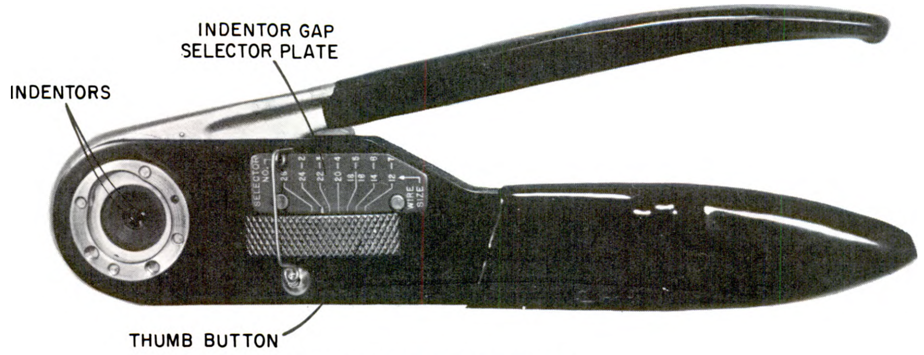
To crimp a terminal, select the proper size and type terminal and insert the prepared wire into the contact pocket until the wire seats on the bottom. The wire should be visible through the inspection hole and the insulation should enter the contact insulation support. Insert the contact and wire into the terminal crimping tool, making sure that the contact is properly seated in the positioner. Actuate the crimping tool handles to crimp the contact and wire. At the completion of the stroke the ratchet releases; open the handles and remove the crimped contact from the tool.

Inspect the crimped terminal and wire. The wire must be visible through the inspection hole. The insulation must be inside the insulation support. The crimping indents must be positioned between the inspection hole and the front of the insulation support. The contact must not be bent. The crimped contact is now ready to be installed into a connector.

For eyeball crimping, remove the head assembly from the tool. Select the proper wire size and move the thumb button until the pointer is alined with the selected wire size



(A) WITH TURRET INSTALLED



(B) WITH TURRET REMOVED

AE.39

Figure 7-14.–Crimping tool MS 3191-3.

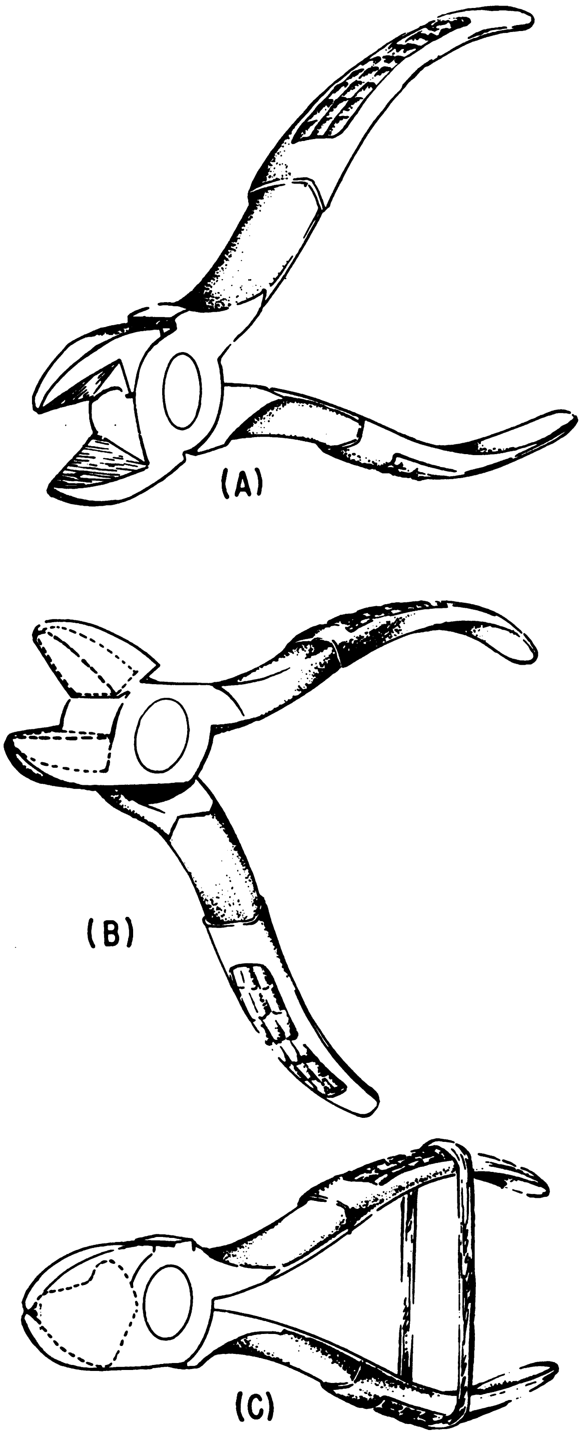
on the indentor gap selector plate. Holding the contact in the crimping tool, slowly close the handles and at the same time position the contact so that the indentors are positioned midway on the contact barrel. Insert the wire, making sure it is bottomed in the contact, then close handles fully.

After releasing the handles, remove and inspect the crimped contact. The contact must not be fractured, and the conductor must be visible in the inspection hole.

DIAGONAL PLIERS

Diagonal pliers are described briefly in Basic Handtools, NavPers 10085-A. The following discussion describes a modification which is advantageous when the diagonal pliers are used in the maintenance of equipment aboard aircraft where working clearances are likely to be close.

The diagonal pliers (fig. 7-15) have been modified by adding potting compound to the jaws. This prevents loss of small pieces of wire into the equipment when cutting wire. The potting compound also allows the technician to cut the wire without holding onto the piece being cut away. (Figure 7-15 (A) shows the diagonals before being modified.) If you do not have a pair of these modified diagonal pliers, manufacture your own by adding potting compound. Before applying the potting compound, clean the diagonals with solvent; then secure the handles with a rubberband (fig. 7-15 (C)) and apply the compound. Allow 24 hours for the compound to dry. The jaws may be separated by slicing them apart with a single edge razor blade.



AT.80

Figure 7-15.—Diagonal pliers. (A) Without compound; (B) with compound; (C) applying compound.

SAFETY WIRING PLIERS

When installing equipment in aircraft, it becomes necessary to lockwire (usually referred to as safety wire) designated parts of the installation. The process of lockwiring can be accomplished faster and neater with the use of special pliers. However, the use of these pliers requires extreme care. The wire must be installed snugly, but not so tight that the part of the wire is overstressed. The routing of the twisted wire is prescribed by the particular installation, and in many instances is designated in the appropriate Maintenance Instructions Manual.

Safety wiring pliers (fig. 7-16) are three-way pliers, which hold, twist, and cut. They are designed to reduce the time used in twisting safety wire on nuts and bolts. To operate, grasp the wire between the two diagonal jaws, and the thumb will bring the locking sleeve into place. A pull on the knob twirls the twister, making uniform twists in the wire. The spiral rod may be pushed back into the twister without unlocking it, and another pull on the knob will give a tighter twist to the wire. A squeeze on the handle unlocks the twister, and the wire can be cut to the desired length with the side cutter. The spiral of the twister should be lubricated occasionally.

MECHANICAL FINGERS

Small articles which have fallen into places where they cannot be reached by hand may be retrieved with the mechanical fingers. This tool is also used when starting nuts or bolts in difficult areas. The mechanical fingers (fig. 7-17) have a tube containing flat springs which extend from the end of the tube to form claw-like fingers, much like the screw holder. The springs are attached to a rod that extends from the outer end of the tube. A plate is attached to the end of the tube, and a similar plate to be pressed by the thumb is attached to the end of the rod. A coil spring placed around the rod between the two plates hold them apart and retracts the fingers into the tube. With the bottom plate grasped between the fingers and enough thumb pressure applied to the top plate to compress the spring, the tool fingers extend from the tube in a grasping position. When the

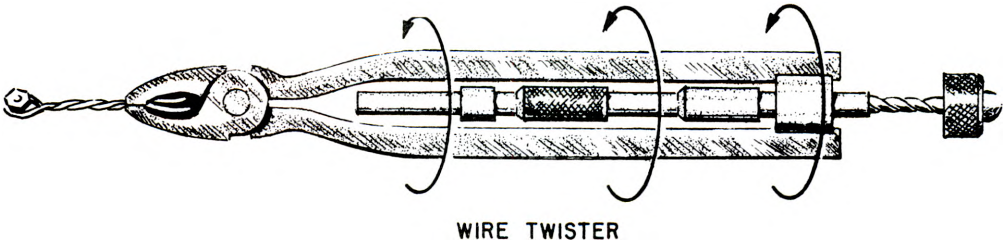


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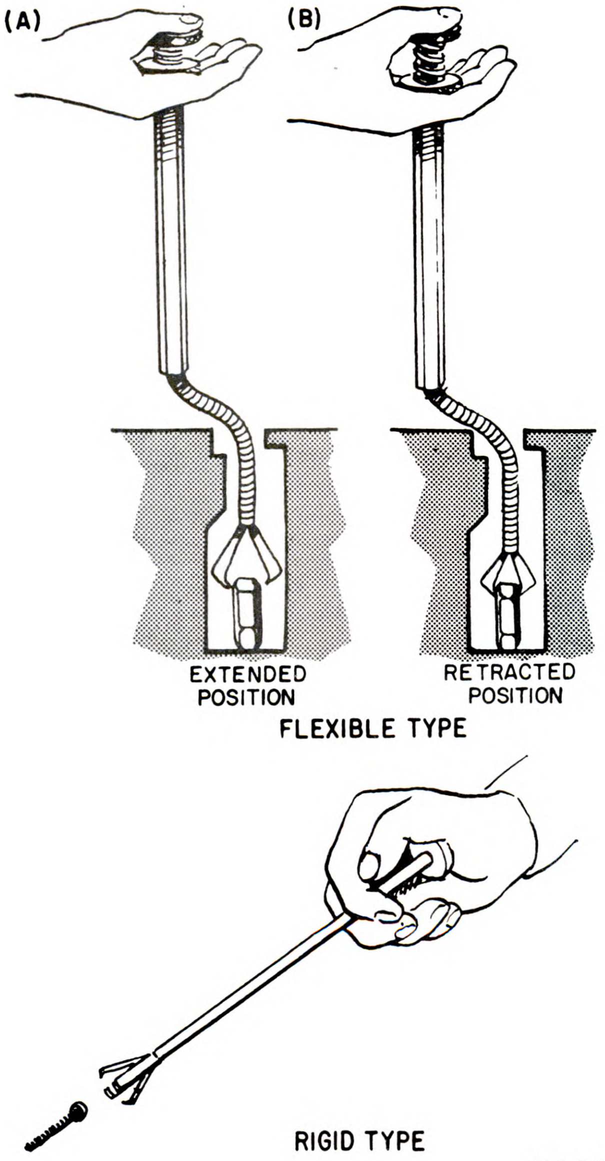
Figure 7-16.–Safety wiring pliers.



AT.82

Figure 7-17.–Mechanical fingers.

thumb pressure is released, the tool fingers retract into the tube as far as the object they hold will allow. Thus, enough pressure is applied on the object to hold it securely. Some mechanical fingers have a flexible end on the tube to permit their use in close quarters or around obstructions.

NOTE: Mechanical fingers should not be used as a substitute for wrenches or pliers. The fingers are made of thin sheet metal and can be easily damaged by overloading.

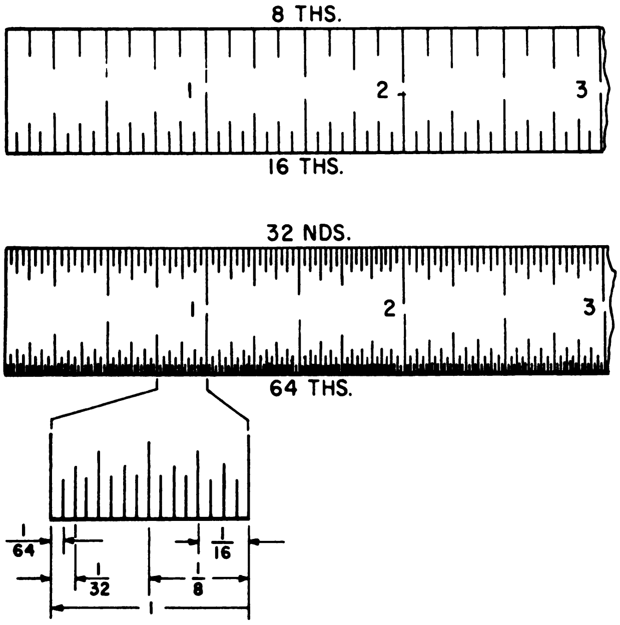
STEEL SCALE

The steel scale (fig. 7-18) is a measuring device that will usually be found in a toolbox. It is graduated in divisions of 1/8 and 1/16 inch on one side and 1/32 and 1/64 inch on the other side. The steel scale most commonly used is 12 inches long.

Measurements are taken with a steel scale by holding it on its edge on the surface of the subject being measured. This will prevent making errors which might be caused by the thickness of the scale. Such thickness causes the graduations to be a slight distance away from the surface of the object. Measurements are read at the graduation which coincides with the distance to be measured.

FLASHLIGHT

Each toolbox should have a standard Navy vaporproof two-cell flashlight. The flashlight is used constantly during all phases of maintenance. Installed in both ends of the flashlight are rubber seals which keep out all vapors. The flashlight should be inspected periodically for the installation of these seals, the spare



AT.83

Figure 7-18.–Steel scale.

bulb, and red lens which are contained in the end cap. NOTE: Do not throw away the red lens; it will be necessary during night operations.

INSPECTION MIRROR

There are several types of inspection mirrors available for use in aircraft maintenance. The mirror is issued in a variety of sizes and may be round or rectangular. The mirror is connected to the end of a rod and may be fixed or adjustable. (See fig. 7-19.)

The inspection mirror aids in making detailed inspection where the human eye cannot directly see the inspection area. By angling the mirror, and with the aid of a flashlight, it is possible to inspect most required areas.

TOOL KITS, SHOP TOOLS, AND TOOL CRIBS

One of the first steps taken when a new man reports for duty in a squadron or activity is to issue him an individual toolbox. The toolbox should contain the low-cost, high-usage handtools that will enable him to perform the tasks assigned. The purpose of the individual handtool kit is to make the necessary tools for performance of line and/or hangar maintenance immediately available to the individual. The contents of the individual handtool kit are among the tools listed in Consumable General Support Equipment for All Types, Classes, and Models of Aircraft, NavAir 00-35QG-016.

Under the crew leader concept of maintenance, the crew leader's kit has the same type tools as the individual handtool kit. It is issued to an individual of a crew, and is to be used by all members of that crew. Thus, the crew leader's handtool kit will have several of the same type and/or size tool where the individual kit has only one.

Shop tools are the larger, low-usage, and special tools for use on specific equipments. A shop tool bin is normally utilized to make available those special tools and medium-usage tools needed to perform the various phases of shop maintenance. However, shop tools also include any handtools required to perform more extensive maintenance than can be accomplished from a toolbox or a crew leader's kit. To determine the types and number of shop tools allowed, refer to the applicable allowance list from the NavAir 00-35QG-0 series.

Frequently, a squadron tool crib has the responsibility for all tools in the squadron, including issuance of tools, inventory of toolboxes, and ordering new tools for replacement of broken or lost tools. A squadron tool crib is set up under the responsibility of the maintenance department. Its purpose is for the stowage and issuance of low-usage handtools and those which are common to more than one shop. Special tools provided by the aircraft manufacturer are also stowed in the tool crib. A complete list of these special tools can be found in the Maintenance Instructions Manual, section one, for each type aircraft.

The tools used in an aircraft maintenance activity are determined by the mission of the activity and the type aircraft to be maintained. In view of this, there is no hard and fast rule as to the type and/or number of tools that may be supplied in the different handtool kits and cribs. The quantity and types of tools allowed for an activity may be found in the appropriate allowance list.

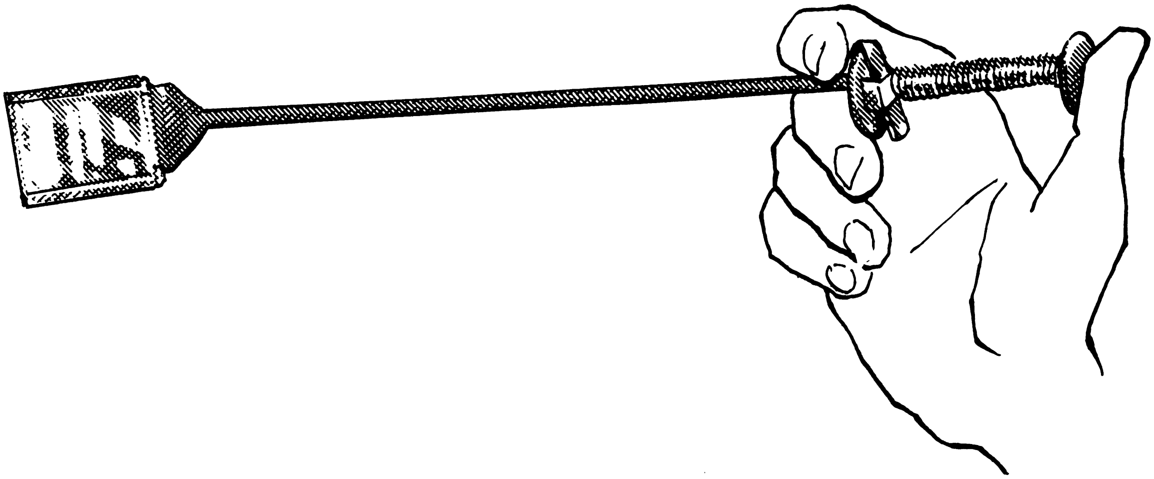


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Figure 7-19.—Typical inspection mirror

AIRCRAFT HARDWARE

MOUNTING PARTS

Items of hardware used when installing equipment in aircraft are specified in the applicable Maintenance Instructions Manual. In all instances, the proper parts should be used; if substitution becomes necessary, care must be taken that the substitute item is satisfactory in all respects.

It is not always desirable to use the same mounting parts that were removed from the installation. Prior to reinstalling the same items, an inspection must be made to insure that the parts are of the type specified, and are not defective or damaged. It must also be determined that instructions do not forbid their reuse. Then, and only then, may the removed parts be reinstalled.

General information regarding such mounting parts as screws, nuts, bolts, washers, etc., is included in the Rate Training Manual Airman, NavPers 10307-B. Aircraft Structural Hardware for Aircraft Repair, NavWeps 01-1A-8, is a valuable source for detailed information.

Substitution of Parts

If the specified mounting parts cannot be obtained, a temporary installation may be made using suitable substitute parts; but these parts should be replaced with the proper items as soon as they can be obtained. When making parts substitutions, special attention must be given to the following considerations:

1. Corrosion. The chemical or metallic composition of the part must be such that its use does not contribute appreciably to the danger of corrosion.
2. Strength. The strength of the substitute part must be the same, or greater than the ones prescribed. (When determining the strength, consideration should be given to the tensile, compression, and/or shear strength, as applicable to the specific use.)
3. Size. Substitute bolts and screws should be the same size as the prescribed item. If a detachable nut is to be used, a different thread may be tolerated; if a threaded hole or an anchor nut is involved, the thread must be the same as the one prescribed. In all cases, washers must have the same inner diameter as the prescribed item, but a different outer diameter or thickness may sometimes be permitted.
4. Length. Substitute screws or bolts must have a length which is sufficient for the particular installation, but must not be so long that they are in the path of any moving part. They must not be in contact with other aircraft items such as electrical wiring, hydraulic lines, etc.
5. Magnetic properties. Specific areas of the aircraft (for example, vicinity of such items as the magnetic compass, magnetic anomaly detection equipment, radio direction finder, or gyros) should not be changed in a manner that

may cause the magnetic fields of the area to become distorted. In these areas, any substitute part must possess the same magnetic properties and characteristics as the one prescribed.

6. Style. Most items of mounting hardware are available in various styles. It is easy to find screws and bolts which are identical in all respects except for the type head. These parts are usually to be preferred as substitutes, provided they possess all required special features.

7. Special features. If a bolt is to be torqued to a given value, a torque wrench which is usable with that type part and which has the proper torque range must be available. If lockwiring is required, the part must have suitable provisions.

8. Lubrication or coating. If specific instructions call for lubrication or coating of the parts, they must be followed for the substitute part as well as for the prescribed part. If no lubrication is permitted, the substitute part is not to be lubricated.

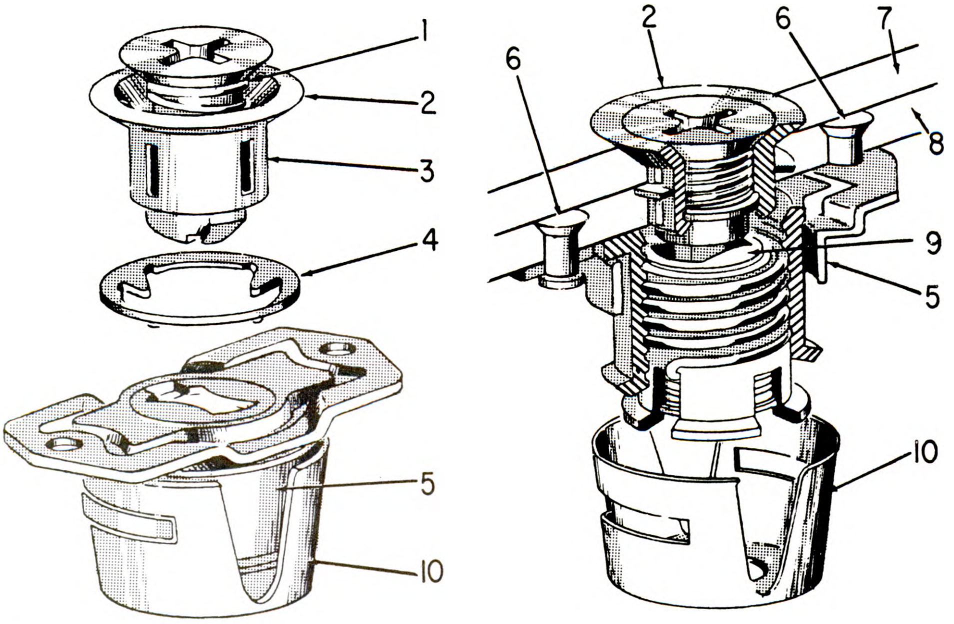
TURNLOCK FASTENERS

Turnlock fasteners are used to secure inspection plates, doors, and other removable panels on aircraft. Turnlock fasteners are also referred to by such terms as quick-opening, quick-action, and stress panel fasteners. The most desirable feature of these fasteners is that they permit quick and easy removal of access panels for inspection and servicing purposes.

Turnlock fasteners are manufactured and supplied by a number of manufacturers under various trade names. Some of the most commonly used are the Camloc stress-panel fastener and Airloc, both of which are discussed in this section. Other turnlock fasteners are covered in the Rate Training Manual Airman, NavPers 10307-B.

Camloc Stress-Panel Fasteners

The Camloc stress-panel fastener (fig. 7-20) is a high-strength, quick-release, rotary



1. Tension spring.
2. Stud assembly.
3. Bushing.
4. Retaining ring.
5. Receptacle assembly.
6. Receptacle attaching rivets.
7. Outer skin.
8. Inner skin.
9. Insert
10. Cover.

AT.85

Figure 7-20.—Camloc stress-panel fastener.

type fastener and may be used on flat or curved, inside or outside panels. The fastener may have either a flush or nonflush stud. The studs are held in the panel with flat or cone-shaped washers, the latter being used with flush fasteners in dimpled holes.

This fastener may be distinguished from screws by the deep No. 2 Phillips recess in the stud head and by the bushing in which the stud is installed. A threaded insert in the receptacle provides an adjustable locking device. As the stud is inserted and turned counterclockwise 1/2 turn or more, it screws out the insert sufficiently to permit the stud key to engage the insert cam when turned clockwise. Rotating the stud clockwise 1/4 turn engages the insert; and continued rotation screws the insert in, tightening the fastener. Turning the stud 1/4 turn counterclockwise will then release the stud but will not screw the insert out far enough to permit reengagement in installation. It is necessary to turn the stud at least 1/2 turn counterclockwise to reset the insert.

To unlock the stress-panel fastener and reset it in the same operation, use a No. 2 Phillips screwdriver (or equivalent), turning the stud counterclockwise 1/2 turn or more. Do not turn the stud past stop.

CAUTION: Do not use a power screwdriver on this fastener.

To lock use a Phillips No. 2 screwdriver (or equivalent) push the stud in and turn clockwise until increased torque is felt; then continue turning until the fastener is tight.

NOTE: When installing a large panel, it may be necessary to engage all the fasteners before tightening. This is done by pushing each stud in and turning it clockwise 1/4 turn. The stud should engage the receptacle but remain loose. If the stud does not engage, it will pop out, indicating that the insert must be reset by turning the stud counterclockwise 1/2 turn or more.

Airloc Fastener

The Airloc fastener consists of a stud, stud cross pin, and a receptacle. (See fig. 7-21.) The stud is attached to the access cover, and is held in place by the cross pin. The receptacle is riveted to the access cover frame. A quarter turn of the stud (clockwise) locks the fastener in place, and turning the stud counterclockwise unlocks the fastener.

THREADED FASTENERS

Threaded fasteners are covered in the Rate Training Manual Airman, NavPers 10307-B. However, a brief discussion of a new development in threaded fasteners is included in this text.

"Torq-Set" Screws

"Torq-Set" machine screws (offset cross-slot drive) have recently begun to appear in new equipment. The main advantage of the newer type is that more torque can be applied to its head while tightening or loosening than any other screw of comparable size and material without damaging the head of the screw.

Torq-Set machine screws are similar in appearance to the more familiar Phillips machine screws.

Since a Phillips driver could easily damage a Torq-Set screwhead, making it difficult if not impossible to remove the screw even if the proper tool is later used, maintenance personnel should be alerted to the differences. (See fig. 7-22.)

ACCOUNTABILITY

A definition of the word accountability is "the state or quality of being responsible—a charge (object) for which one is responsible or accountable." The Navy has a code that is called Material Accountability Recoverability Codes (MARC's). These codes appear in column 3 of the Section G Allowance List, NavAir 00-35-QG-0 Series and are illustrated by the following examples:

Code:

B—Exchange consumables—requiring old items for replacement items such as items containing precious metal, highly pilferable items, or certain high cost items. Example: Drill, electric portable, FSN 9Q 5130-226-5384.

C—Consumables—expendables. Example: Stripper, wire, FSN 9Q 5110-268-4220.

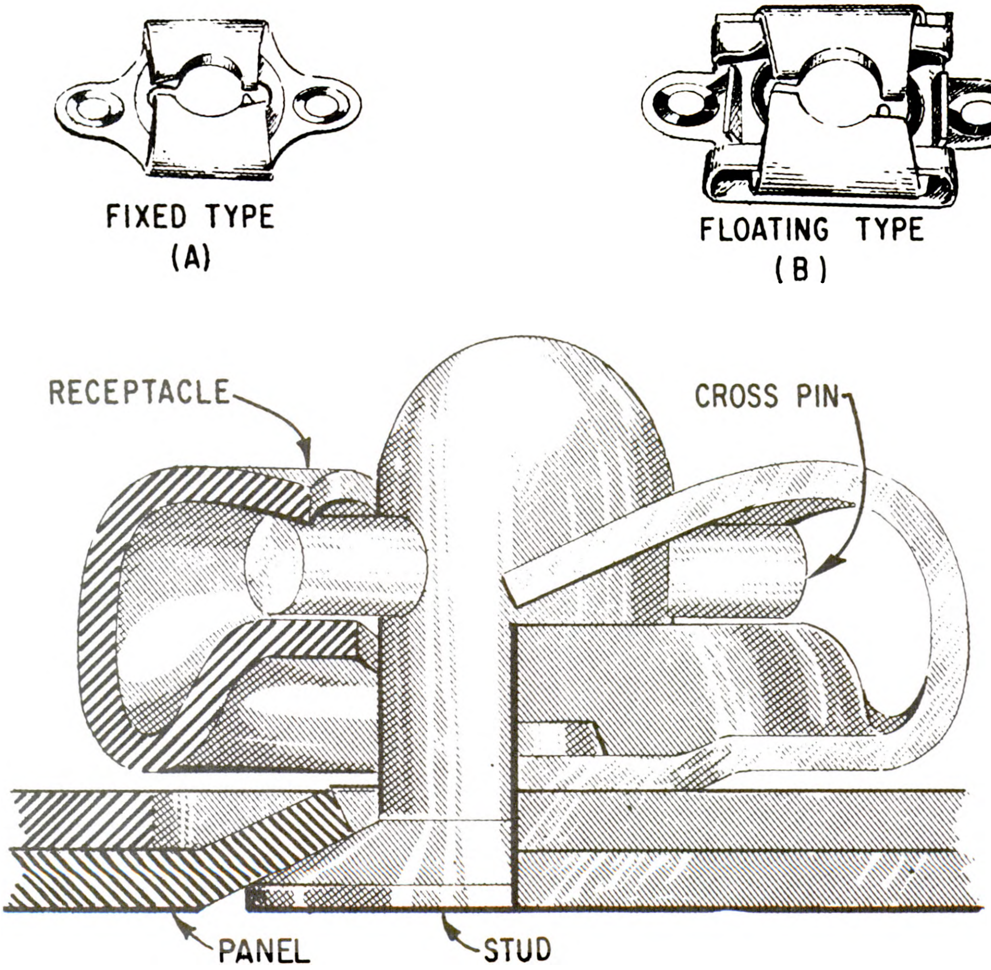


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Figure 7-21.—Airloc fastener.

ALLOWANCE LISTS

Allowance lists are lists of equipments, material, and/or tools made available to an organization for performance of maintenance.

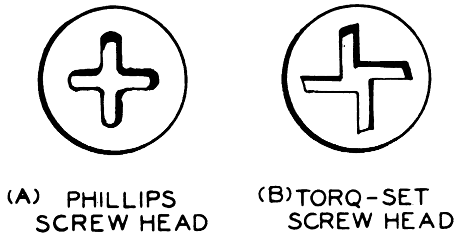
NavAir 00-35QG-0 Series

These allowance lists contain allowances of shop and general support equipment and material which will be made available for maintenance support of aircraft as may be assigned or supported by the following levels of maintenance:

1. Intermediate level (shop).
2. Organizational level (hangar/line).
3. Advanced base components, excluding Aircraft Fleet Marine Force activities supported by tables of basic allowances.

CUSTODIAL RESPONSIBILITY

Most handtools are not feasibly repairable. Due to this fact and their original low cost (compared to shop tools), they are classed as consumable. However, the activity must pay for replacements. Therefore, it is the duty of each individual to help eliminate the need for replacements. One method of accomplishing this is by carrying an inventory of tools in your toolbox so that upon completion of a job you can be sure that all of the tools are ac-



AT.87

Figure 7-22.—Comparison of Phillips and Torq-Set screwheads.

counted for. A tool that has been lost represents a waste of funds; in addition, it is a definite liability. If it has been left loose in an aircraft, it can become a dangerous missile when the aircraft is launched or when the aircraft is performing violent maneuvers.

Inventory Requirements

The basic objective of an inventory is to insure a proper balance between the supply of, and the demand for, those tools required for the efficient operation and maintenance of a squadron or maintenance activity. To accomplish this objective it is necessary that tools be identified and cataloged to provide accurate knowledge of the tools being used. Each item should be accounted for every 30 to 90 days in accordance with squadron instructions. The number of handtools on hand in relation to the number required by the activity should be indicated by the inventory.

Reordering Tools

Tools are reordered as the inventory requirements dictate. Usually the senior petty officer or his delegate reorders all tools—both shop tools and those for individual toolboxes, as they are needed. However, squadron or maintenance activity policy is followed in all cases.

It is unwise to wait until the number of tools needed is too large, as it is easier for the supply department to fill a small order rather than a large one.

Tools are ordered by reference to Consumable General Support Equipment for All Types, Classes, and Models of Aircraft, NavAir 00-35QG-016.

CHAPTER 8

ELECTRONIC TEST EQUIPMENT

Other chapters of this manual discuss the basic principles and concepts of some of the equipment which the technician may encounter. An understanding of the theory of operation of these equipments forms only a portion of the knowledge necessary to successfully perform the maintenance tasks required. A thorough knowledge of electrical and electronic test equipment is also needed.

All electronic test equipment is designed and constructed to perform tests of one or more specific types. These tests are used to determine the proper operation or alinement of electronic sets, circuits, or parts. The performance of electronic ASW units in the aircraft is determined by the accuracy of the test equipment used to calibrate and aline them and the care with which the technician performs these jobs. Without test equipment very few electronic devices could be used; therefore, it follows that every technician should learn to use test equipment properly.

The test equipments discussed in this chapter are typical of the ones currently in use in the fleet. No attempt is made to include theory beyond that necessary to describe the operation of the test set under discussion. Whenever the technician must use a piece of test equipment with which he is not familiar, he should always consult the appropriate instruction manual. These publications contain detailed and specific information on the particular equipment. The purpose of this chapter is to discuss some of the different test equipments from the standpoints of operation and general operational and maintenance procedures.

CARE AND USE OF TEST EQUIPMENT

All electronic maintenance shops are provided with a variety of test equipment to be used in maintaining the many different types of electronic units its supports. However, there are very few spare test sets. When a test set becomes inoperative, shop maintenance suffers. Therefore, every man must use the test equipment only for the purposes and in the manner for which it was designed. Protect the equipment from physical harm that may result from dropping, falling, or any other careless misuse, and always observe proper operating techniques.

One of the chief causes of test set failure is carelessness. The user can be careless in operating procedure or in handling the set. The usual carelessness in operating procedure is improper selection of range for the quantity to be measured, such as attempting to measure 250 volts on the 50-volt scale of a meter. If there is any doubt about proper usage of a test set, it is wise to refer to the manual issued with the set.

Much damage to test equipment results from improper handling. Technicians often place test sets near the edge of the bench where they can easily be knocked off or pulled off by the test leads. Read the instructions for proper handling and operating procedure, and think while using the equipment.

CALIBRATION

Most test sets require occasional checks to determine if they are within operating tolerances. Some test sets are used as frequency standards and require periodic calibration. In every case the recommendations of the manual or pamphlet issued with the set should be followed, unless those recommendations have been changed by current instructions.

Calibration is normally performed in a shop that is equipped with special purpose test sets. It is seldom accomplished at the organizational level of maintenance.

REPAIR

Minor repair of test sets is often accomplished at the organizational level of maintenance. When calibration of the set is not involved. Repairs are usually limited to replacement of test leads and fuses. Current instruction on repair of test equipment should be consulted before attempting any repairs of a major nature.

HANDLING PRECAUTIONS

Some equipments may require special handling; however, there are several precautions which apply to test equipments in general. Rough handling, moisture, and dust all affect the useful life of such devices. Bumping or dropping a test instrument, for example, may destroy the calibration of a meter or short circuit the elements of an electronic tube within the instrument. Creasing or denting coaxial test cables will alter their attenuating effect, thereby affecting the accuracy of any RF measurements made with these cables in the circuit.

To reduce the danger of corrosion to untreated parts, always store test equipment in a dry place when it is not in use. Excessive dust and grime inside a test equipment also affects its accuracy. Be sure that all the assembly screws which hold the case of the test equipment in place are tightened securely. As an added precaution, all dust covers should be placed on test equipments when they are not in use.

Meters are the most delicate parts of test equipments. In order to insure that the meter will maintain its accuracy, these additional precautions should be followed:

1. Make certain that the amplitude of the input signal under test is within the range of the meter.
2. Keep meters as far away as possible from strong magnets.
3. When servicing an item of electronic equipment which contains a meter, disconnect the meter from the circuit before making resistance or continuity tests.

(The latter precaution will eliminate the possibility of burning out the meter.)

The instructions for properly stowing test equipment cables and other accessories, as set forth in the instruction manuals accompanying the equipment, should be carefully read and strictly followed. Improper stowage of accessories results in changes in cable characteristics, intermittent shorts in cables and leads, and, in general, causes unreliable test equipment indications.

MEASURING INSTRUMENTS

The term "measuring instruments," as used in this discussion, includes only that class of test equipments which measure the basic parameters of an electronic equipment. The basic parameters are (in this application) voltage, current, resistance, power, frequency, and field intensity.

The discussion of measuring instruments includes test equipment classes designated as multimeters, electronic voltmeters, power measuring devices, frequency meters, and field intensity measuring devices.

REVIEW OF METER OPERATION

There must be some source of power available to operate a meter. Some meters are powered by batteries installed in the meter case, others are supplied through an electrical power cord which is plugged into a power receptable; a vacuum tube volt meter (VTVM) is an example of the latter type. The power to operate some meters (such as the megger) is produced by manual operation of a handcrank. Each of these three types are described in the following paragraphs.

Most meters are designed to be used for measuring more than one electrical quantity, and are called multimeters. Before discussing any one particular type meter, a brief review of each of the basic meters is presented.

Ammeter

The amplitude of current flow through the basic meter mechanism limits it to measuring a fixed range of only a fraction of an ampere. To overcome this limitation, and to protect the mechanism, a current shunt is used. This device, which is actually a resistance of low value, permits the instrument to serve as a d-c ammeter in the measurement of relatively large direct currents.

The current distribution between meter movement and shunt is inversely proportional to their individual resistances. Thus, the shunt (which has less resistance) carries the majority of the current. Since the meter coil carries only a small portion of the circuit current, it is capable of indicating relatively large values of circuit current. The instrument may be adapted to a variety of current ranges by the use of shunts of different values which are switched in or out as required. Figure 8-1 shows a simplified schematic diagram of an ammeter-section taken from a typical volt-ohm-milliammeter.

Ohmmeter

For any given ohmmeter, midscale deflection is obtained when the current drawn by the meter is one-half the value of the current at full-scale (zero ohms) deflection. This condition exists when the resistance being measured is equal to the total meter circuit resistance. Analysis of the circuit in figure 8-2, shows the full-scale deflection is obtained when the meter probes are shorted together, and that less than full-scale deflection is obtained when the resistance to be measured, R_X, is connected into the circuit. If the meter now reads one-half of its former current, it follows that the total curcuit resistance has doubled, indicating that R_X is equal to the total meter circuit resistance.

Since the ohms-calibrated scale is nonlinear, the midscale portion represents the most accurate portion of the scale. However, the usable range extends with reasonable accuracy on the high end to ten times the midscale reading, and on the low end to one-tenth of the midscale reading.

To extend the range of an ohmmeter, the proper values of shunt and series resistors and battery voltages are connected into the circuit so that with the test leads shorted the meter will read full scale. Figure 8-3 shows a simplified schematic diagram of an ohmmeter section taken from a typical volt-ohm-milliammeter.

Voltmeter

To make the basic meter mechanism suitable for measuring d-c voltages, the voltage multiplying resistor is added. The voltage multiplying resistor is placed in series with the coil (fig. 8-4) and limits the flow of current to a safe value.

Since the value of the resistor is constant for any given application, the flow of current

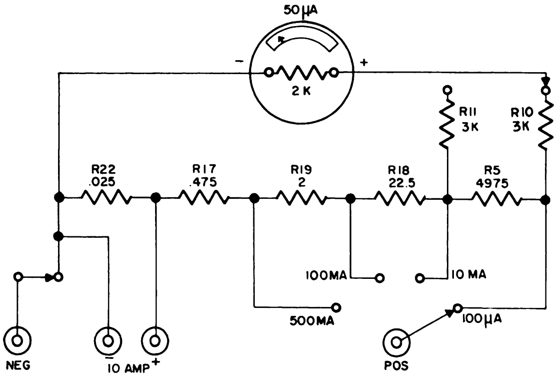


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Figure 8-1.—Simplified schematic diagram of an ammeter.

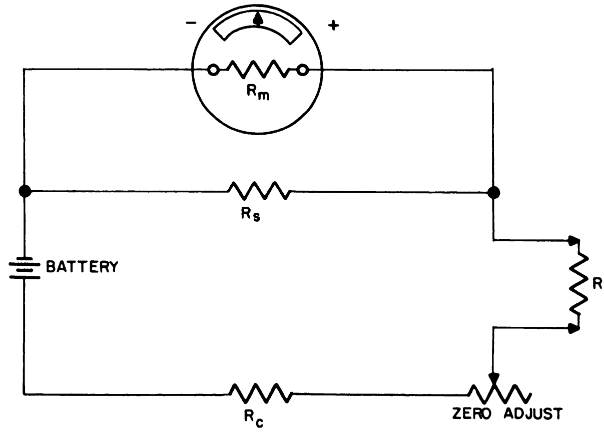

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Figure 8-2.—Series type ohmmeter basic circuit.

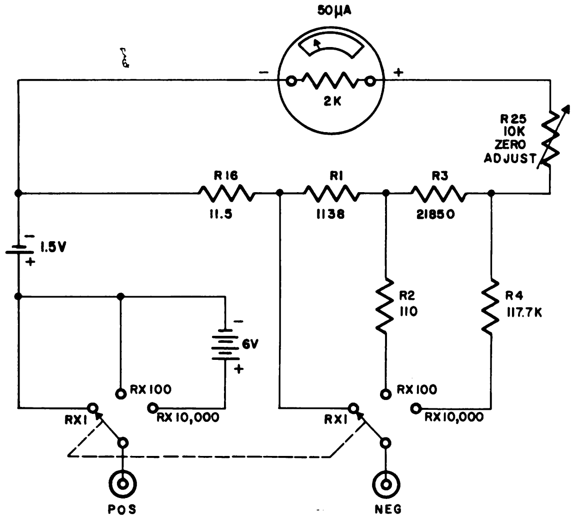

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Figure 8-3.–Simplified schematic diagram of an ohmmeter.

through the coil is proportional to the voltage under measurement. By proper calibration of the dial, the instrument may be made to indicate voltage although it is actually activated by currents. In practice, the voltage ranges of the instrument are established by the use of different values of multiplying resistors.

NONELECTRONIC METERS

Much of the technician's work requiring the use of a volt-ohm-milliammeter can be accomplished with a portable, battery operated multimeter. Many shops employ the TS-352, Simpson 260, or the PSM-4 for field use (troubleshooting in the aircraft, for instance). The technician will, however, often need a more sensitive meter–one that gives more accurate readings and has wider ranges.

Equipment schematics and wiring diagrams often specify that voltages indicated at test points were obtained by using a meter of a certain sensitivity, such as a 20,000-ohms-per-volt meter. A meter of the same sensitivity should be used when repairing that equipment in order to obtain accurate readings.

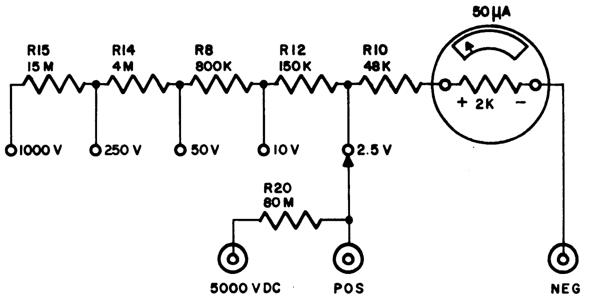

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Figure 8-4.–Simplified schematic diagram of a d-c voltmeter.

Multimeter AN/PSM-4C

This multimeter is a portable, general purpose, nonelectronic instrument designed for general electrical and electronic service and maintenance functions. Multiple ranges are provided for resistance, a-c and d-c voltages, and current. Test results are indicated directly on a wide-faced panel meter. It employs a 20,000-ohms-per-volt movement to provide accurate measurement on low voltage ranges.

Range and function selectors and a meter adjusting control are provided. This meter is designated as a replacement for the TS-352 series multimeters, although the older type is still in fairly common usage.

Milliohmmeter AN/USM-21A

The AN/USM-21A low range ohmmeter can measure resistances in the range of 10 milliohms or less. Most ohmmeters read zero at such a low value. Several troubleshooting problems can be solved easily with such an instrument. One of the most common and troublesome is to find the exact location of a short circuit in a power distribution circuit involving many parallel paths.

In using the milliohmmeter, several problems are encountered. These problems include stray circuit resistances such as contact resistance, test lead resistance, and switching resistance. In using the conventional low range ohmmeters, the primary limitation is in the contact resistance at the test probes.

The AN/USM-21A was designed principally to overcome the contact resistance problem.

A measured current is passed through the test circuit by means of a heavy set of clip leads. Using an auxiliary set of test leads which carry very little current, the resulting voltage drop across the test circuit is measured by a sensitive millivoltmeter which senses this voltage.

Megger

A megger is an instrument that applies a high voltage to the component under test and measures the current leakage of the insulation. Thus a capacitor or insulated cable can be checked for leakage under much higher voltages than an ohmmeter is capable of supplying. It consists of a hand-driven, d-c generator and an indicating meter. The name megger is derived from the fact that it measures resistances of many megohms.

There are various resistance ratings of meggers with full-scale values as low as 5 megohms, and as high as 10,000 megohms. Figure 8-5 shows the scale of a 100-megohm, 500-volt megger. Notice that the upper limit is infinity and that the scale is crowded at the upper end. The first scale marking below infinity represents the highest value for which the instrument can be accurately used. Thus, if the pointer goes to infinity while making a test, it means only that the resistance is higher than the range of the set.

There are also various voltage ratings of meggers (100, 500, 750, 1,000, 2,500 etc.). The most common type is the one with a 500-volt rating. This voltage rating refers to the maximum output voltage of the megger. The output voltage is dependent upon the speed of turning of the crank and armature. When the megger's armature rotation reaches a predetermined speed, a slip clutch will maintain the armature at a constant speed. The voltage rating is important, for the application of too high a voltage to even a good component will cause a breakdown. In other words, do not use a 500-volt megger to test a capacitor rated at 100 volts.

Meggers are used to test the insulation resistance of conductors in which shorting or breaking down under high voltage is suspected. In some situations, meggers are used in the prevention of unnecessary breakdowns by maintaining a record of insulation resistance of power and high voltage cables, motor and generator windings, and transmission lines. These records will reflect fluctuations in resistance and aid in determining when the components should be replaced to prevent a breakdown.

Meggers are used for testing capacitors whose peak voltages are not below the output of the megger. They are also used for testing for high resistance grounds or leakage on such devices as antennas and insulators.

Precautions to be followed in the use of the megger are as follows:

1. When making a megger test, the equipment must not be energized. It must be disconnected entirely from the system before it is tested.
2. Observe all rules for safety in preparing equipment for test and in testing, especially when testing installed high voltage apparatus.
3. Use well-insulated test leads, especially when using high range meggers. After the leads

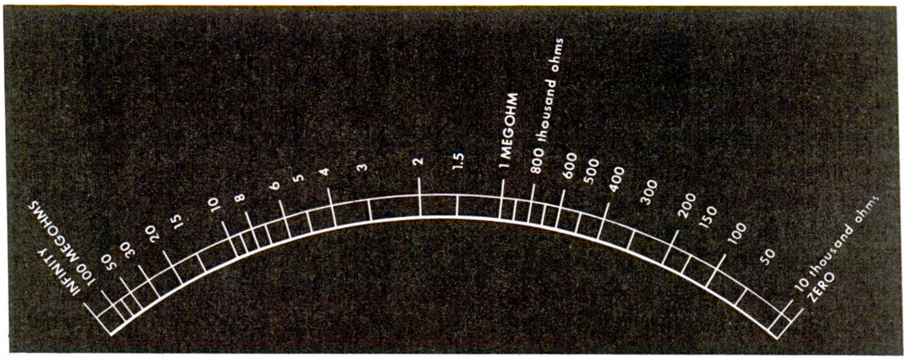

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Figure 8-5.—Scale of 100-megohm, 500-volt megger.

are connected to the instrument and before connecting them to the component to be tested, operate the megger and make sure there is no leak between the leads. The reading should be infinity. Make certain the leads are not disconnected or broken by touching the test ends of the leads together while turning the crank slowly. The reading should be approximately zero.

4. When using high range meggers, take proper precautions against electric shock. There is sufficient amount of capacitance in most electrical equipment to "store up" sufficient energy from the megger generator to give a very disagreeable and even dangerous electric shock. Owing to a high protective resistance in the megger, its open circuit voltage is not as dangerous, but care should be exercised.

5. Equipment having considerable capacitance should be discharged before and after making megger tests in order to avoid the danger of receiving a shock. This can be accomplished by grounding or short circuiting the terminals of the equipment under test.

ELECTRONIC METERS

Electronic meters are used primarily for the same purposes as are the nonelectronic meters. Some characteristics of their operation, however, give them definite advantages. In the electronic multimeter, the current and resistance measuring circuits function in a manner identical to the corresponding nonelectronic measuring instruments. The measurement of voltage, however, involves the use of an amplifier which in turn requires that the meter be calibrated prior to use.

Proper calibration and use of the instruments vary slightly according to model. Details are included in the Operation Instruction Manual for each model.

The ordinary voltmeter has several disadvantages that make it practically useless for measuring voltages in high impedance circuits. For example, suppose that the plate voltage of a pentode amplifier is to be measured. (See fig. 8-6.) When the meter is connected between the plate and cathode of the electron tube, the meter resistance R_m, is placed in parallel with the effective plate resistance R_{eff}, thereby lowering the effective plate resistance. The effective plate resistance is in series with the plate load resistor, R_L, and this series circuit appears across the supply voltage, E_{bb}, as a voltage divider. Since the overall resistance is lowered, it follows that current through R_L will also increase, the voltage drop across R_L will also increase, and the voltage drop across R_{eff} will decrease. The result is an incorrect indication of plate voltage, and is called loading effect.

Calculation of Loading Effects

Before the voltmeter is connected, the plate current is determined by the effective resistance of the plate circuit, the plate load resistor, and the plate voltage. If the tube has an effective resistance of 100,000 ohms, a plate load resistance of 100,000 ohms, and the plate power supply is constant at 200 volts, then the plate current is

$$\frac{200\text{v}}{200{,}000\Omega}$$

or 0.001 ampere. The plate voltage (plate to cathode) is 0.001 x 100,000, or 100 volts.

Assume that the voltmeter used to measure the plate voltage of the tube has a sensitivity of 1,000 ohms per volt and that the selected meter range is from 0 to 250 volts. The meter will then have a resistance of 250,000 ohms. This resistance in parallel with the tube resistance of 100,000 ohms produces an effective resistance of 71,400 ohms in series with the plate load resistor. The total resistance across the

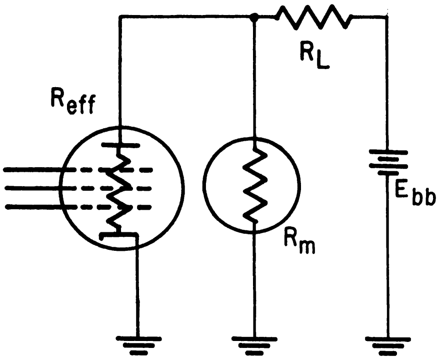

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Figure 8-6.–Loading effect created by meter resistance.

B supply is therefore 171,400 ohms instead of the 200,000 ohms before the meter was applied, and the current through the plate load resistor is

$$\frac{200\text{ v}}{171{,}400\Omega},$$

or 0.00117 ampere. Across the plate load resistor the voltage drop is 0.00117 x 100,000, or 117 volts, and the plate-to-cathode voltage on the tube is 200-117, or 83 volts when the meter is connected, thus causing an error of 17 volts. The lower the sensitivity of the meter, the greater the error will be; in this example, the error of 17 volts when the reading should be 100 volts is a 17 percent error.

A meter having a sensitivity of 20,000 ohms per volt and a 250-volt maximum scale reading would introduce an error of about 1 percent. However, in circuits where very high impedances are encountered, such as in grid circuits of electron tubes, even a meter of 20,000 ohms per volt sensitivity would impose too much of a load on the circuit.

VTVM Advantages

Another limitation of the alternating current, rectifier type voltmeter is the shunting effect at high frequencies of the relatively large capacitance of the meter's rectifier. This shunting effect may be eliminated by replacing the usual metallic oxide rectifier with a diode electron tube; the output of the diode is applied to the grid of an amplifier in which the plate circuit contains the d-c meter. Such a device is called an electron tube voltmeter or a vacuum tube voltmeter, usually abbreviated VTVM. Voltages at frequencies up to 500 megahertz, and sometimes even higher, can be measured accurately with this type of meter. The frequency limitation is determined by the model of VTVM.

The input impedance of a VTVM is large, and therefore the current drawn from the circuit whose voltage is being measured is small and in most cases negligible. The main reason for using a vacuum tube voltmeter is to overcome the loading effect by taking advantage of the VTVM's extremely high input impedance. A VTVM that is used extensively for electronics maintenance is contained in the TS-505 multimeter.

Vacuum Tube Voltmeter TS-505

Figure 8-7 shows a front panel view of the TS-505. The VTVM measures d-c voltages from 0.05 volt to 1,000 volts (in 9 ranges), and a-c voltages from 0.05 volt to 250 volts rms (in 7 ranges), at frequencies from 30 Hz to 1 MHz. With the RF adapter that is used with the d-c voltage measurement circuit, RF voltages may be measured from 0.05 volt to 40 volts rms at frequencies from 500 kHz to 500 MHz. D-c resistances from 1 ohm to 1,000 megohms may be measured.

The accuracy of this meter is good, being 5 percent for d-c voltages and 6 percent for a-c and RF voltages. The meter movement requires 1 ma for full-scale deflection.

The input impedance to the meter is 6 megohms at audiofrequencies, 40 megohms on

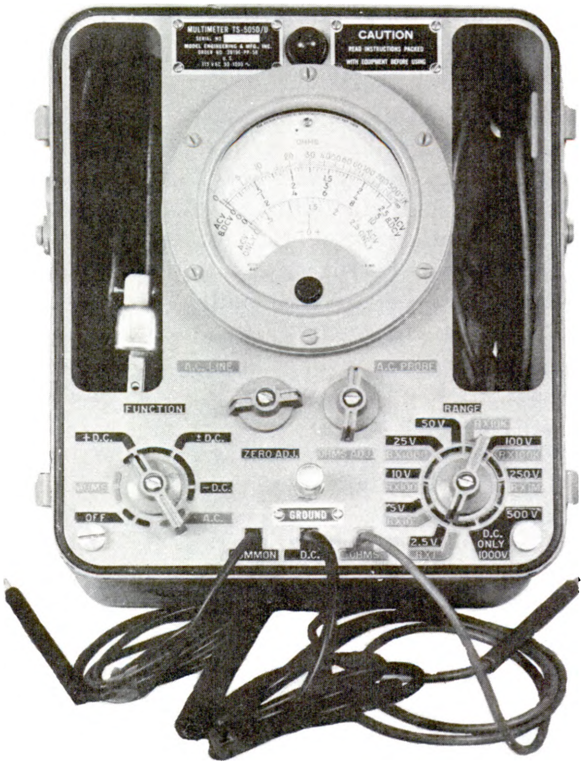

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Figure 8-7.—TS-505 multimeter, front panel.

the 1,000-volt d-c range, and 20 megohms on all other ranges.

The power requirement is 98 to 132 volts, single phase, 50 to 1,000 Hz, at about 21 volt-amperes.

The removable cover of the TS-505 contains accessories such as alligator clips, an RF adapter, and miniature probe tips. The miniature tips slip over the regular tips when working in confined areas.

OPERATING CONTROLS.–The controls that you will use when operating the meter (fig. 8-7) are as follows:

1. FUNCTION switch: Selects the type of multimeter operation desired and turns the multimeter on or off.
2. RANGE switch: Selects various voltage or resistance measurement ranges.
3. ZERO ADJ. control: Controls pointer of indicating meter. Used to set the meter pointer at zero on the +DC, -DC, AC, or OHM scale, or at midscale on the ±DC scale.
4. OHMS ADJ. control: Controls pointer of indicating meter. Used to set the meter pointer at ∞ on the OHMS scale when the FUNCTION switch is set on OHMS position.
5. Meter: Indicates the value of voltage or resistance measured.
6. AC LINE cord: Connect multimeter to a-c power source.
7. COMMON probe: Connects the ground, or common circuit of the multimeter, to the equipment under test.
8. DC probe: Connects equipment under test to the d-c measuring circuit of the multimeter.
9. OHMS probe: Connects equipment under test to the ohmmeter circuit of the multimeter.
10. AC probe: Connects equipment under test to the a-c measuring circuits of the multimeter.
11. Pilot light indicator: Lights when power is applied to the multimeter.

TECHNIQUES FOR USE.–The operation of this meter is virtually self-explanatory. By studying the controls and their respective markings, you should be able to determine the steps to follow when making a particular measurement. Do not attempt to use this instrument unless you have studied the technical manual which sets forth the operating procedures, or unless you have been instructed in its proper usage, under the direction of your shop supervisor.

Two peculiarities of this meter are:

1. In order for it to indicate accurate readings it must warm up. This usually takes about 10 minutes. During this period the meter pointer may drift rapidly; this is normal.
2. Voltage measurements cannot be read directly on the meter scale when the function switch is set at the ±DC position.

The purpose of the ±DC position (zero center scale) is to determine the polarity of an unknown d-c voltage or to indicate a zero d-c voltage input to the multimeter.

CAUTION: The maximum d-c voltage which may be applied to the multimeter when the function switch is set at the ±DC position is one-half of the voltage indicated by the panel marking opposite the range switch setting.

The major difference between any VTVM and a conventional multimeter is that the VTVM utilizes a vacuum tube in its input. For a detailed explanation of the circuitry of the TS-505 VTVM consult the manufacturer's manual or the Operation and Service Instruction Manual.

Phase Angle Voltmeters

The overall accuracy of many electronic equipments is determined by measuring phase angles in computing transformers, computing amplifiers, and resolver systems. In the past, one of the most common methods used for measuring phase shift or phase angles between signals was observing patterns on an oscilloscope. With this method, it was hard to determine small angles, and difficult to translate various points into angles and sines of angles. The most limiting factor in using oscilloscope patterns developed when one of the signals contained harmonic distortion or noise.

In any complex waveform containing a fundamental frequency and harmonics, measuring phase shifts presents problems. In most applications, interest lies in the phase relationship of the fundamental frequency, regardless of the phase relationship of any harmonics which may be present. One of the requirements of a phase measuring device is to measure the phase difference between two discrete frequencies, regardless of the phase and amplitude of other components of the waveform.

The basic block diagram of a phase angle voltmeter is shown in figure 8-8. There are two inputs–the signal and the reference. Both channels contain filters which pass only the fundamental frequency. All other frequencies are highly attenuated. Each channel has a variable amplitude control and amplifiers to increase the variety of signals that can be checked.

A calibrated phase shifter is inserted into one channel; that channel signal can be phase shifted to correspond to the other channel. This is detected in the phase detector and observed on the meter.

The calibrated phase shifter is made up of a switch (whose position corresponds to the 0°, 90°, 180°, and 270° phase shift) and a potentiometer (whose dial is calibrated from 0° to 90°). The total phase shift is made up of the sum of the two readings.

The phase detector is a balanced diode bridge type demodulator. Its output is proportional to the signal frequency amplitude times the cosine of the angle of phase difference between the signal input and the reference input.

If the reference input is phase shifted until it is in phase or 180° out of phase with the signal input, the output from the phase detector is proportional to the signal input amplitude (the cosine of the angle is unity). If the reference input is phase shifted until it is 90°or 270° from the signal input, the phase detector output is zero (the cosine of the angle is zero).

The point at which the two signals are in phase or 180° out of phase is the point of maximum deflection on the meter. The difference between the in phase and the 180° out of phase points is in the direction in which the needle swings–not the distance it swings. As the point of maximum deflection is approached, the rate of change of the meter reading decreases because the cosine has a small rate of change near 0°. This makes it difficult to read the exact point of maximum deflection.

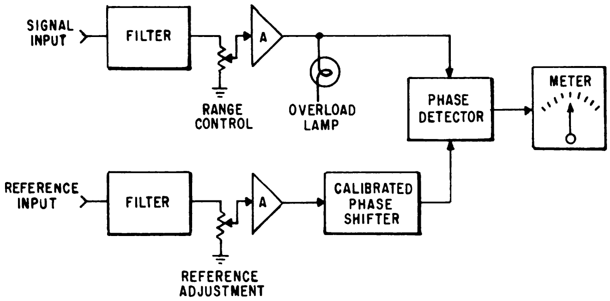

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Figure 8-8.–Phase angle voltmeter, block diagram.

Because the cosine has a maximum rate of change as it approaches 90 (and thus gives a better indication on the meter), most commercial voltmeters are set to determine the point at which the signals are 90° out of phase–"quadrature." When the voltmeter is set for this point, there must be some way of converting the phase shifter reading so that it shows the correct amount of phase shift rather than 90°more or less than the actual amount. Some confusion exists in this area because different manufacturers have different methods of determining the signal quadrant. Manufacturers also differ on whether the final reading is a leading or a lagging phase shift. This means the technician must be familiar with as many types of phase angle voltmeters as the Navy has in the field. He cannot assume that the method he uses to determine phase angle on one type of meter can be used on another; nor can he assume that, because one meter gives him a leading angle between signal and reference waveforms, another manufacturer's meter also gives leading phase shift.

Differential Voltmeter

The differential voltmeter is a realible precision item of test equipment. Its general function is to compare an unknown voltage with an internal reference voltage, and to indicate the difference in their values. The differential voltmeter in most common use in Navy applications is the 803D/AD (fig. 8-9), manufactured by the John Fluke Co. The remaining portion of this discussion is based on that instrument.

The 803D/AD is usable as an electronic voltmeter, as a precision potentiometer, and as a megohmmeter. It can also be used to measure the excursions of a voltage about a reference value. Ease of operation, inherent protection from any accidental overload, and high reliability of readings are additional advantages of the instrument. It is accurate enough for precision work in calibration laboratories, yet rugged enough for general shop use.

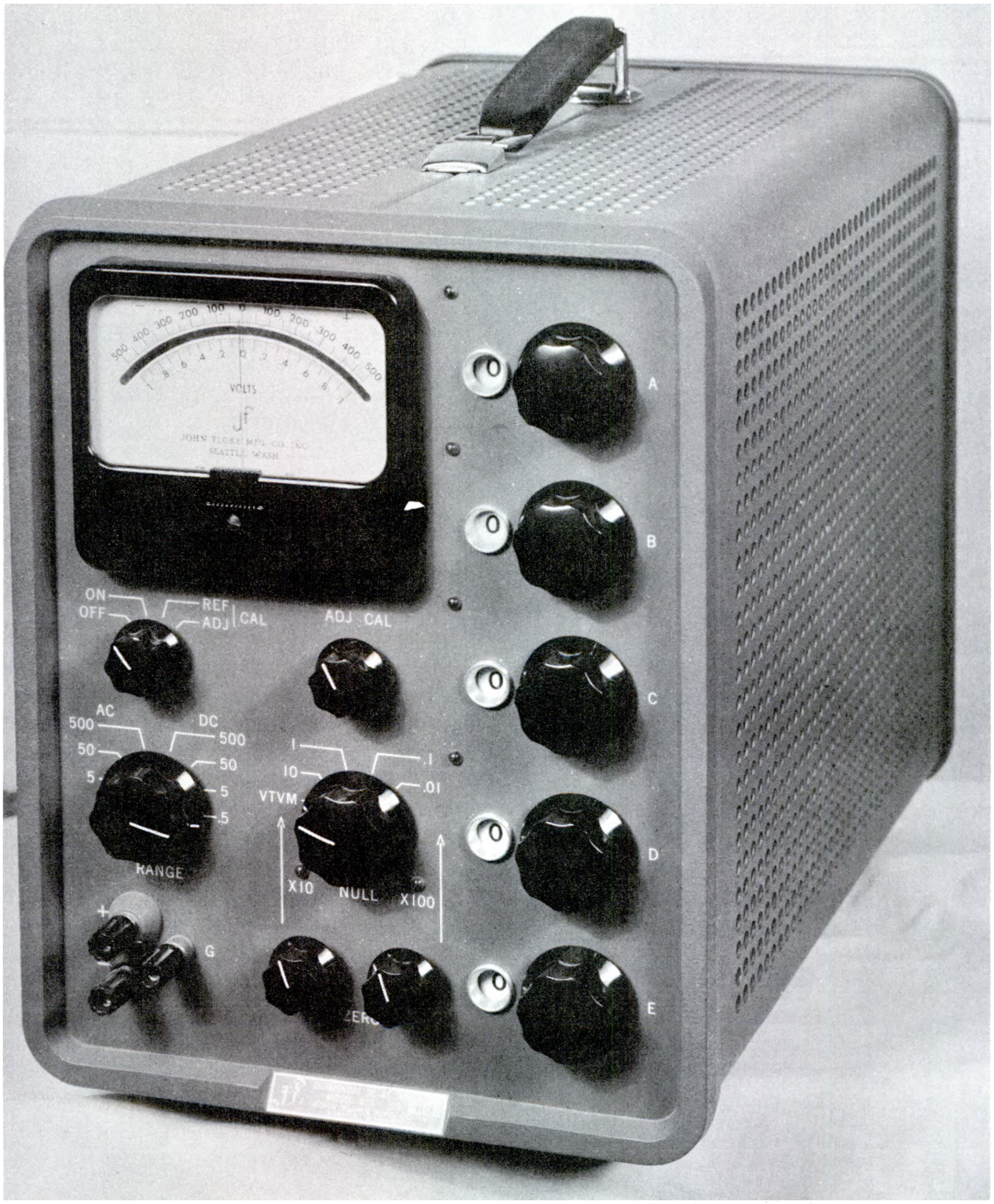

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Figure 8-9.—Differential voltmeter, Model 803D/AD.

The heart of the unit is a precision 500-volt d-c reference power supply. This 500 volts can be precisely divided into increments as small as 10 microvolts by means of 5 voltage dials. Unknown a-c or d-c voltages are matched against the precise internal voltage until no deflection occurs on the panel meter. The unknown voltage is then simply read from the voltage dials. In the highest null sensitivity range, a potential difference between unknown and reference voltage as small as 0.01 volts causes full scale meter deflection.

At null, the differential voltmeter presents an "infinite" input impedance to the voltage under measurement, almost completely eliminating circuit loading.

A functional schematic diagram of the differential voltmeter is shown in figure 8-10. The principal circuit divisions are as follows:

1. A 500-volt d-c reference power supply.
2. Precision voltage divider network.
3. VTVM.
4. Chopper-amplifier.
5. Converter and converter power supply.

The system circuitry is designed with two separate common returns. One of these, the return for the converter power supply and reference power supply, provides a safety factor for personnel and a capability for measuring a potential difference between two voltages. The other, which is the common return of the VTVM power supply, is connected to the known reference voltage output from the precision voltage divider network. This arrangement provides a constant d-c voltage of +108 volts across the differential amplifier regardless of the d-c potential applied to the grid.

D-C REFERENCE POWER SUPPLY.–A full wave rectifier with its associated filter network supplies a d-c voltage of approximately 1,000 volts to a conventional electron controlled voltage regulator. The regulated output is maintained at 500 volts ±0.01 percent.

In the 500 V DC position, the RANGE switch (S2E) passes this 500 volts directly to the precision voltage divider. In the 50 V DC, 5 V DC, and 0.5 V DC positions, range resistors S2F divide the reference voltage to 50, 5, and 0.5 volts d.c., respectively. In all a-c positions of the RANGE switch, only 5 volts of the reference supply is used, due to the fact that the maximum output of the a-c to d-c converter is 5 volts.

PRECISION VOLTAGE DIVIDER.–Each of the four precision voltages available from the reference supply must be made adjustable through a precision divider network so that unknown voltages may be nulled or matched exactly. The five decade resistor strings (fig. 8-11) accomplish this function.

Note that each string, with the exception of the first, parallels two resistors of the string that precedes it. Between the two wipers of S4, there is a total resistance of 40K and a total

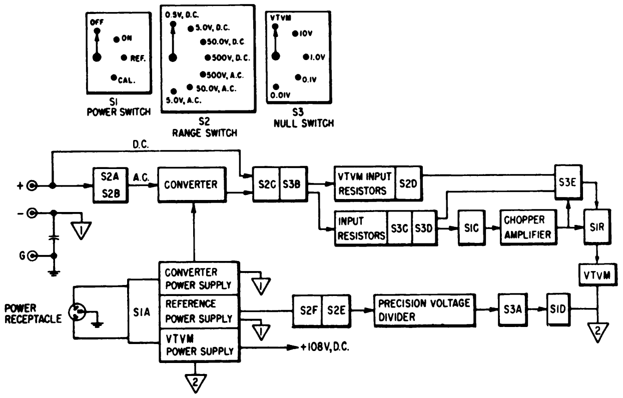

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Figure 8-10.—Differential voltmeter, functional schematic diagram.

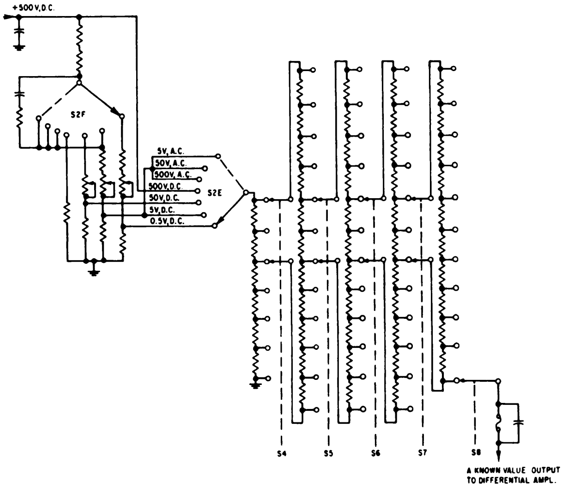

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Figure 8-11.–Precision voltage divider.

voltage of 100 volts d.c. with the RANGE switch in the 500 V DC position. Across the wipers of S5, S6, and S7, there are 10, 1, and 0.1 volts d.c., respectively. Switch S8 selects increments of 0.01-volt d.c. from the last decade. These voltages are reduced by a factor of 10 for each successively lower voltage range.

All resistors of each decade are matched and all decades are matched for each instrument, providing an overall divider accuracy of 0.005 percent.

With the NULL switch in any null range, the output of the precision voltage divider appears at the grid of one-half of the VTVM differential amplifier. A one two-hundredths ampere (5 milliampere) fuse protects this output.

VACUUM TUBE VOLTMETER.—When operating in the differential mode, output voltage from the precision voltage divider appears on the grid of V4B, one-half of the differential amplifier. (See fig. 8-12). The unknown voltage appears on the grid of V4A, the other half of the differential amplifier. Any difference between these potentials is indicated by the meter coupled between the cathodes of V4A and V4B. When the output voltage exactly matches the unknown, the meter reads zero and no current is drawn from the source being measured, because the same potential exists on both sides of the input resistances.

When used as a conventional VTVM, the grid of V4B is connected to the 0-volt bus, or negative binding post. With the range switch in the 0.5 V DC position, the unknown voltage appears directly on the grid of V4A and the meter indicates the approximate value of the unknown. Input divider resistors maintain the 0 to 0.5 grid voltage range for all instrument voltage ranges. The input resistance of the instrument in the VTVM position is 10 megohms.

CONVERTER.—All a-c measurements are made by first converting the a-c input to a d-c voltage. The converter provides a maximum d-c output of 5 volts for a maximum a-c input of 5 volts rms. In the 5 V AC position, range switch sections of S2A and S2B couple the converter amplifier input directly to the binding post. In the 50 V AC and 500 V AC positions, input attenuators reduce the unknown a.c. to provide a maximum of 5 volts a-c input to the first converter amplifier.

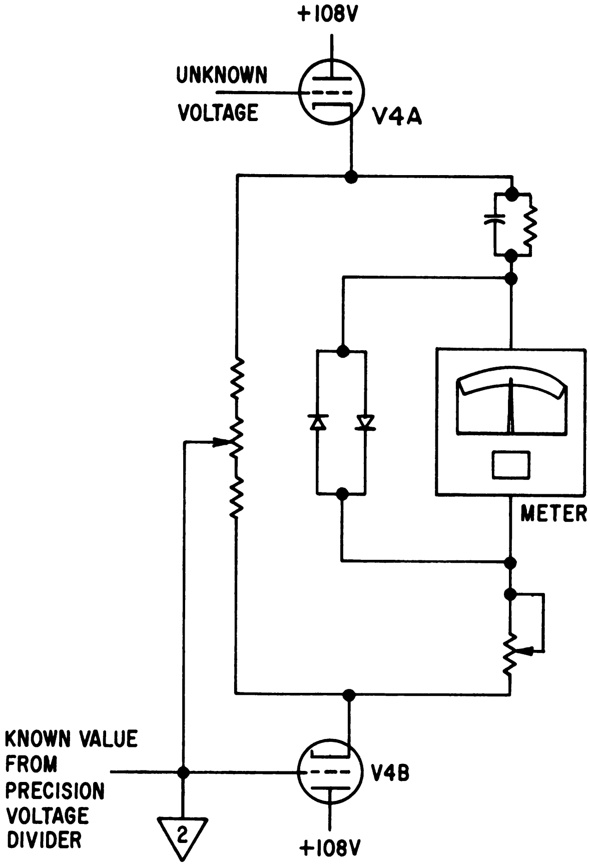

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Figure 8-12.—Differential amplifier.

The overall frequency response of the converter is essentially flat from 30 Hz to 10 kHz.

Repair

The procedures for repairing a defective VTVM are basically the same as for any other electronic equipment. The first step is to sectionalize the fault to the circuit responsible for the abnormal operation of the equipment. The second step is to localize the fault. Localization means tracing the fault to the defective part responsible for the abnormal condition.

Some faults, such as burned-out resistors, arcing, shorted transformer, leaky capacitors, or broken wires, often can be located by sight, smell, and hearing. The majority of faults, however, must be localized by checking voltages and resistances. For further information on troubleshooting and repair of test equipment, see the manual applicable to the equipment involved, the Handbook of Test Methods and Practices NavShips 91828(A), and the Electronics Installation and Maintenance Book-Test Methods and Practices, NavShips 900,000.103.

POWER MEASUREMENTS

It is often necessary to check the power consumption and the input and output signal power levels of electronic equipment. The determination of d-c power is comparatively simple; the unit of power (the watt) is the product of the potential in volts and the current in amperes. Therefore, a few basic circuit measurements may be taken and the power computed by means of Ohm's law.

To make accurate a-c power measurements, the phase angle of the voltage and current must be considered. The measurement of a-c power is further complicated by the frequency limitations of various power meters. If there is no phase difference, a-c power may be computed in the same manner as d-c power, by determining the average value of the product of the voltage and current.

Electric power at a line frequency of approximately 60 Hz may be measured directly by a dynamometer type wattmeter. This type of meter (discussed in Basic Electricity) indicates the actual power; and therefore, the phase angle of the voltage and current does not have to be determined. Normally, the exact power consumption of equipment is not necessary for maintenance, and a current measurement is sufficient to decide whether the power consumption is within reason.

In the audiofrequency range, power levels have to be determined in the course of routine checks and during corrective maintenance procedures. When working with audiofrequency amplifiers, it is ordinarily easier and more convenient to measure voltage, current, and impedance and then compute the power than it is to measure power directly.

Power measurements for audiofrequency circuits are usually indicated in terms of decibels (db), decibels referenced to 1 milliwatt (dbm), or volume units (vu). The power gain of an amplifier can be expressed in db. The power level of a sinusoidal signal compared to a 1-milliwatt reference is indicated in dbm. The power level of a complex signal, such as voice, music, or multiplexed information, compared to a reference level of 1 milliwatt is indicated in vu.

Many a-c voltmeters have scales calibrated in decibels or voulume units. Such meters are useful for making measurements where direct indication in decibels is desired. However, it must be remembered that these are voltmeters, and that power measurements are not meaningful unless the circuit impedance is known. (The topic of decibels is discussed in some detail in Basic Electronics.)

At radiofrequencies below the UHF range, power is usually determined by voltage, current, and impedance measurements. One common method, used to determine the output power of RF oscillators and radio transmitters, consists of connecting a known resistance to the equipment output terminals, measuring the current flow through the resistance, and then calculating the power as the product of I^2R. Since the power is proportional to the current squared, the meter scale can be calibrated to indicate power units directly. A thermocouple ammeter is usually used for measurement of RF current. The resistor used to replace the normal load is usually specially designed to have low reactance, and has the ability to dissipate the required amount of power. Such resistors are commonly called "dummy loads" or "dummy antennas."

In the UHF and SHF portion of the radiofrequency spectrum, it is usually difficult to accurately measure the voltage, current, and impedance. These basic measurements may change greatly at slightly different points in a circuit, and are appreciably affected by small changes in the placement of parts in the vicinity of the tuned circuits. To measure the output of microwave radio or radar transmitters, test instruments which convert RF power to another form of energy, such as light or heat, can be used to indirectly measure the power. A method which measures the heating effect of a resistor load on a stream of passing air can be used. Accurate measurement of large magnitude power can be achieved by measuring the temperature change of a water load. The most common type of power meter for use in this frequency range employs a bolometer. The bolometer is a loading device that undergoes changes of resistance as changes in the power dissipation occur. Resistance is measured before and after RF power is applied, and power can be determined by the change in resistance.

Field Intensity and Noise

The magnitude of the electric field of a radio wave at a given point is known as the "field intensity" or "field strength" of that wave, and is usually measured in terms of millivolts or microvolts per meter. The field strength of a radio wave is determined by measuring the RF voltage induced in a receiving antenna. The unit of field strength is the volt per meter; but since the actual values of induced voltage are quite small, the microvolt per meter is a more convenient unit in practical applications.

Several types of test equipment are available for the measurement of field strength and noise. They are known as "radio test sets," "field strength meters," and "radio noise meters." These instruments can be used to indicate either the relative or the absolute magnitude of the field intensity of the energy radiated by a transmitter antenna. The equipment necessary for a specific test is determined by the frequency of the signal to be measured and the accuracy required. Field strength and noise measurements are required to determine antenna efficiency, directivity characteristics, and signal coverage. This information is valuable for selecting antenna sites and for detecting spurious harmonic radiation. Interference, either radiated or conducted, can be detected and located by the use of radio test sets.

The measurement of relative field strength can be made with rather simple test equipment; sometimes a grid-dip meter will suffice. Other test equipment circuits utilize a pickup antenna and a diode (or crystal) detector in connection with a microammeter. In circuits using this combination, the meter reading indicates the relative strength of the field acting on the pickup antenna, and is not directly proportional to the field intensity because of the nonlinearity of the detector.

More elaborate test equipment, for the measurement of absolute field intensity, compares the voltage induced in a pickup antenna with a voltage generated by a self-contained calibrated oscillator. The antenna is connected to a sensitive receiver, which usually incorporates two calibrated attenuators, one between the antenna and mixer stage, and the other in the first IF amplifier stage. A meter in the test equipment measures the diode current in the second detector and indicates the field intensity, usually in terms of microvolts per meter.

In (A) of figure 8-13, a schematic of a simple type of crystal detector field strength meter is shown. The crystal detector is mounted in the center of a pickup antenna, whose length ideally is one-half wave at the frequency of the received signal. The crystal is coupled to a 0-1 milliammeter through radio frequency choke coils. The induced signal is rectified by the crystal, and the resulting current is indicated on the milliammeter. This type of meter is used at distances of four or five wave lengths from the transmitting antenna and for low power transmitter measurements.

In (B) of figure 8-13, a schematic of a considerably more sensitive field strength meter is shown. Tube V1 is an RF amplifier, the output of which is impedance coupled to the diode section of V2, a detector amplifier. The rectified signal voltage is developed across R1, one end of which is attached to the filament-cathode of the amplifier tube. The voltage developed across R1 controls the plate current of V2 which is read on the milliammeter in the plate lead. The amount of change in the plate current is an indication of the strength of the signal induced in the pickup antenna of the field strength meter.

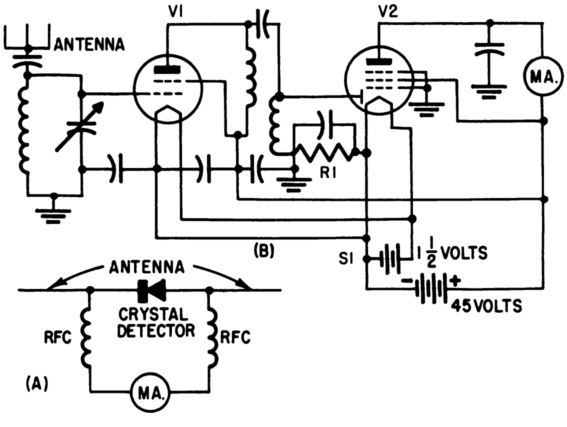

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Figure 8-13.—Field strength meters.

Tube V2 is a variable mu pentode. In this type of amplifier, large signal voltages are amplified by a relatively small amount, and small signal voltages receive much greater amplification. The e_c-i_b curve of such a tube is essentially a logarithmic curve. As a result of this fact, the meter in vacuum tube field strength circuits of this type can be calibrated directly in decibels, a logarithmic unit of power or voltage level.

When using field strength meters, errors and erratic readings can be caused by the presence of objects or persons near either the radiating source or the test meter, resulting in shadows and reflections in the radiated field.

The antenna of the test meter should always be extended to its full length so as to keep its effect on the tuning circuit constant.

Many types of field strength indicators are intended for use within 25 feet of the equipment being tested when antenna adjustments are made to achieve maximum radiation. The distance which results in the most satisfactory operation of the instrument for this test varies with the type of equipment being tested. Usually it is desirable to select a distance for the measurements which give a meter reading at about half-scale.

Standing Waves

It is often desirable to determine how much of the generated RF power is actually radiated from the antenna, or more specifically, to check the transmission line for losses. This test is made by using a standing wave ratio meter. There are different types of standing wave ratio meters. All are similar in that they indicate the amount of power produced by the transmitter as compared to the amount of power reflected from the antenna back to the transmitter. The MM-706 is a typical standing wave ratio meter.

The MM-706 is a small portable instrument that may be employed to read directly the RF power output of a transmitter; incident power, reflected power, and net power delivered to a load; and the voltage standing wave ratio (VSWR) of the associated transmission line. It also provides a means of monitoring the modulation on an AM carrier.

This instrument may also be used as an absorption type wattmeter by employing an appropriate dummy load resistor adapter supplied for that purpose.

The unit may be installed permanently in a transmitting system to provide continuous indications, or it may be used only during tuning and test procedures. The output of the transmitter under test is attached to one end of the coupler unit, and the load (or antenna) is connected to the other end.

The coupler unit has negligible effect on the operation of the transmitter or the load. A sample of the RF energy passing through the coupler is applied to the indication circuit of the instrument. The RF energy is rectified by a series crystal unit and applied to the indicator meter.

The particular function of the instrument is selected by means of a switch on the front panel. If remote indication is desired (a remote meter, or headphones), the lead to the remote indicator is connected through the jack on the front panel. When a remote indicator is used, the circuit to the local meter is opened.

Figure 8-14 is a schematic diagram of the meter. Coupler Z2 is connected in the line between the transmitter and the antenna. RF power passes through this unit. This power is sampled by means of a pickoff in Z2 and coupled through the crystal unit CR2 to P2. The prop-

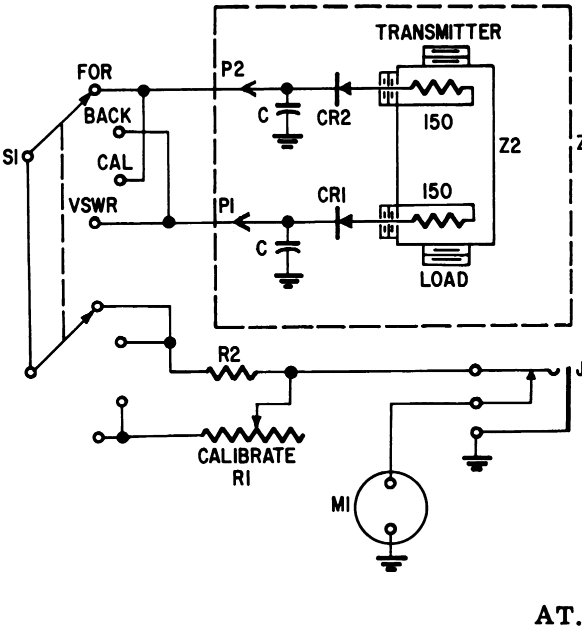

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Figure 8-14.—MM-706 VSWR meter, schematic.

erties of CR2 are such that in the direction indicated by the arrowhead in figure 8-14 the resistance is low; whereas in the opposite direction, the resistance is very high and conduction is practically negligible.

When S1 is in the FOR position, the sampled RF power is rectified by CR2 and applied through the two sections of the switch, resistor R2, and the normally closed contacts of J1 to the meter.

Filtering of the rectified voltage is obtained by means of a capacitor built into the cap which secures the crystal units in the plugs.

When S1 is placed in the BACK position, the sampled RF power is taken from the load end of coupler Z2. Rectification occurs in the same manner as previously explained, and meter M1 reads the reflected power.

The standing wave ratio of a transmission line is the ratio of the maximum RF power to minimum RF power. With S1 in the CAL position, the meter is reading forward power or, almost directly, the power output of the transmitter. The circuit to the meter bypasses fixed resistor R2 and includes potentiometer R1. This potentiometer is adjusted to produce full scale deflection of the meter. This is the maximum power.

Placing the selector switch in the VSWR position causes the RF power at the load end of the coupler unit to be sampled. At this point the reflected power from the antenna back toward the transmitter is bucking the forward power. Therefore, the load end is a low power point. Since the meter was set for full scale deflection at the maximum power point, the reading obtained from the low power point is a direct indication of the voltage standing wave ratio.

FREQUENCY MEASUREMENT

Frequency measurements are often an essential part of preventive and corrective maintenance for electronic equipment. Rotation frequencies of some mechanical devices must be determined. The output frequency of electric power generators is checked when the engine is started and during preventive maintenance routines. Equipment which operates in the audiofrequency range must be adjusted to operate at the correct frequencies. Radio transmitters must be accurately tuned to the assigned frequencies to provide reliable communications and avoid interfering with radio circuits operating on other frequencies. Radar sets must be properly tuned to obtain satisfactory performance.

The rotation frequency of rotating machinery such as radar antennas, servomotors, and other types of electric motors can be measured by the use of a stroboscope. Stroboscopic methods compare the rate of one mechanical rotation or vibration with another or with the frequency of a fluctuating source of illumination. Tachometers can be used to measure the rotation frequency of armatures in electric motors, dynamotors, and engine-driven generators.

The electrical output frequency of a-c power generators can be measured directly by vibrating reed, tuned circuit, or crossed-coil iron-vane type meters. The vibrating reed device is the simplest type of frequency meter, and has the advantage of being rugged enough to be mounted on generator control panels. It is also used to check the line voltage in the shop to insure that the proper frequency is supplied to the equipment and/or test sets.

Frequency Meters

"Frequency meter" is a term generally applied to denote an item of test equipment which is used to indicate the frequency of an external signal. Although some models of frequency meters generate signals having a basic frequency, they should not be confused with that class of test equipment known as signal generators. (Signal generators are discussed later in this chapter.) The signal generator develops a frequency used to operate an external circuit; the frequency meter measures the frequency of a signal developed in an external circuit.

As mentioned previously, some frequency meters generate a signal frequency; others do not. The group in which no frequency is generated internally is properly called a "wavemeter." Wavemeters are of two basic types—reaction and absorption. Those frequency meters which do generate an internal frequency may use either electronic or mechanical oscillation as the frequency generator.

Measurement Methods

Frequency measurements in the audiofrequency range can be made by the comparison method or by a direct-reading frequency meter. Frequency comparisons can be made by the use of a calibrated audiofrequency signal generator in conjunction with either an oscilloscope or a modulator and a zero-beat indicator device. Direct-reading frequency measurements can be made by instruments using series frequency-selective electrical networks, bridge test sets having null indicators, or counting type frequency meters.

Frequency measurements for radio equipment are made during tuning, preventive maintenance, and corrective maintenance procedures. The type of test equipment selected depends on the frequency to be measured and the required accuracy. Signal frequencies of radio transmitters which operate in the low frequency to the VHF range are normally measured by absorption type wavemeters, reaction type wavemeters, heterodyne type frequency meters, or calibrated radio receivers. Where accuracy is not of prime importance, rapid frequency checks may be made by the absorption type wavemeter. Since the wavemeter is relatively insensitive, it is very useful in determining the fundamental frequency in a circuit generating multiple harmonics. Calibration of test equipment measure signals in this frequency range can be checked by comparison with standard frequency signals broadcast by the National Bureau of Standards.

The signal frequencies of radio and radar equipment which operate in the UHF and SHF range can be measured by resonant cavity type wavemeters, resonant coaxial line type wavemeters, or Lecher-wire devices. When properly calibrated, resonant cavity and resonant coaxial line wavemeters are more accurate and have better stability than wavemeters used for measurements in the low frequency to VHF range. These frequency-measuring instruments are often furnished as part of communication and electronic equipment, but are also available as general purpose test sets.

Heterodyne Type Meters

Heterodyne type frequency meters are available in several varieties. Although they all function in the same general manner, some differences exist in the manner of accomplishing their purpose.

Test instruments of this class generate a signal within the test set. This signal is mixed with a signal from the equipment under test to obtain a beat frequency. The frequency of one signal is then changed to obtain a zero beat. (The beat frequency is the difference frequency which results from heterodyning two signals. A zero beat is obtained when heterodyning two signals of the same frequency.) The frequency of the unit under test may be determined by reading the frequency indicator of the test set.

A heterodyne type frequency meter usually consists of a heterodyne oscillator, an RF harmonic amplifier, a crystal-controlled oscillator, a mixer or detector, a modulator, an AF output amplifier, and a means for indicating frequency. (See fig. 8-15.) Most models are furnished with a set of calibration charts giving the dial readings for the frequencies listed, together with a table of the crystal harmonics; thus a complete and accurate frequency coverage over the designed range is provided. Some models indicate the frequency directly on dials.

The crystal-controlled oscillator operates at a fixed frequency, but is also capable of emitting various harmonic frequencies of the crystal for use as check frequencies. These checkpoints are then used for adjusting the heterodyne oscillator, thus insuring more accurate operation. Provisions are usually made within the crystal-controlled oscillator for precise adjustment to its assigned fundamental frequency.

The TS-186D/UP test instrument is a general purpose, crystal-controlled, heterodyne

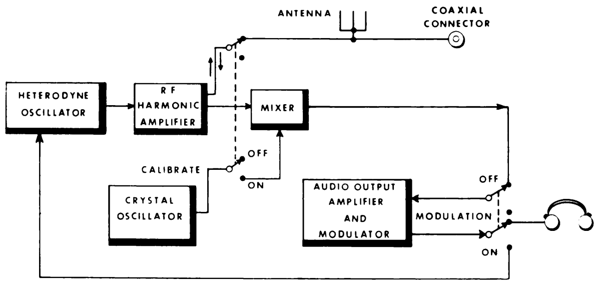

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Figure 8-15.—Crystal-calibrated heterodyne frequency meter, block diagram.

type frequency meter used to measure the frequency of transmitters, oscillators, or signal generators. It provides both visual and aural indications of signal frequency by means of a beat indicating meter, headphones, and a video output jack for observation on an oscilloscope, as desired. A vernier tuning dial and an associated calibration chart are used in making frequency measurement determinations. The instrument is usable for either field or depot level maintenance testing.

The RF input is routed through waveguide and coaxial cable to a detector mixer, where it is mixed with the output of a heterodyne oscillator. From these inputs, the difference signal is then routed through an audio amplifier. A crystal oscillator, when substituted for the input signal, is used to check the frequency calibration of the heterodyne oscillator. This checking is done at specified checkpoints near the frequency at which the frequency measurement is to be made.

A d-c milliammeter is included for the following functions:

1. Help to indicate a zero beat.
2. Measure the grid current of the crystal oscillator when used.
3. Measure the cathode current of the detector mixer.
4. Measure the cathode current of the heterodyne oscillator.
5. Measure the cathode current of the various indicators.

A selector switch determines which value is to be measured. The indicator circuit causes a dip in meter reading near the zero-beat indication. The meter, however, does not respond to frequencies less than 100 Hz; therefore, a pair of headphones is used to provide more accurate indications of zero beat. The video output is obtained through a jack in the output of the detector mixer circuit.

The instrument is usable for CW, MCW, or pulsed signals in the frequency range of 100 to 10,000 MHz, with signal input magnitudes of 500 μ v to 1 v. The bandpass of the audio amplifier is 100 kHz, to 100 kHz; audio output impedance is 600 ohms. For airborne use, the equipment is usable up to altitudes of 10,000 feet without requiring additional pressurization.

Wavemeters

Wavemeters are calibrated resonant circuits used to measure frequency. Although the accuracy of wavemeters is not as high as that of heterodyne frequency meters, they have the advantage of being comparatively simple and can be easily carried about.

Any type of resonant circuit may be used in wavemeter applications. The exact kind of circuit employed depends on the frequency range for which the meter is intended. Resonant circuits consisting of coils and capacitors are used for low frequency wavemeters. Butterfly circuits, adjustable transmission line sections, and resonant cavities are used in VHF and microwave instruments.

There are three basic kinds of wavemeters—the absorption, the reaction, and the transmission types.

Absorption wavemeters are composed of the basic resonant circuit, a rectifier, and a meter for indicating the amount of current induced into the wavemeter. In use, this type of wavemeter is loosely coupled to the circuit to be measured. The resonant circuit of the wavemeter is then adjusted until the current meter shows a maximum deflection. The frequency of the circuit under test is then determined from the calibrated dial of the wavemeter.

The reaction type derives its name from the fact that it is adjusted until a marked reaction occurs in the circuit being measured. For example, the wavemeter is loosely coupled to the grid circuit of an oscillator, and the resonant circuit of the meter is adjusted until it is in resonance with the oscillator frequency.

The setting of the wavemeter dial is made by observing the grid current meter in the oscillator. At resonance, the wavemeter circuit takes energy from the oscillator, causing the grid current to dip sharply. The frequency of the oscillator is then determined from the calibrated dial of the wavemeter.

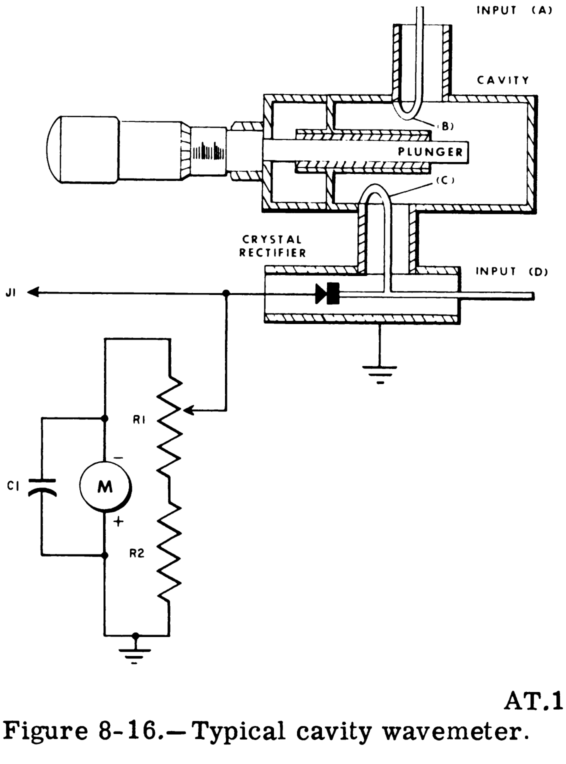
This type is commonly referred to as a "grid-dip" meter, and is discussed in Basic Electronics.

The transmission wavemeter is an adjustable coupling link. When it is inserted between a source of radiofrequency energy and an indicator, energy is transmitted to the indicator only when the wavemeter is tuned to the frequency of the source. Transmission wavemeters are widely used in measuring microwave frequencies. Units of this type are included in echo boxes. The additional provisions for echo boxes permit additional testing functions.

Many actual wavemeters are used in performing various functions. Cavity type wavemeters are the type most commonly used, and only this type is discussed in detail.

Cavity Wavemeters

Figure 8-16 shows a typical cavity wavemeter. The wavemeter illustrated is of the type commonly used for the measurement of microwave frequencies. The device employs a resonant cavity which effectively acts as a high-Q, LC tank circuit. The resonant frequency of the cavity is varied by means of a plunger which is mechanically connected to a micrometer mechanism. Movement of the plunger into the cavity reduces the cavity size and increases the resonant frequency. Conversely, an increase in the size of the cavity (made by withdrawing the plunger) lowers the resonant frequency. The microwave energy from the equipment under test is fed into the wavemeter through one of two inputs, A or D. A crystal rectifier then detects (rectifies) the signal, and the rectified current is indicated on the current meter, M.



AT.103
Figure 8-16.—Typical cavity wavemeter.

This specific instrument can be used as either a transmission type or an absorption type wavemeter. When used as a transmission wavemeter, the unknown signal is coupled into the circuit by means of input A. When the cavity is tuned to the resonant frequency of the signal, energy is coupled through coupling loop B into the cavity and out through loop C to the crystal rectifier. It is rectified and current flow resulting from this rectification is indicated on the meter. At frequencies off resonance, little or no current flows in the detector and the meter reading is small. The micrometer and attached plunger are varied until a maximum meter reading is obtained. The micrometer setting is then compared with a calibration chart supplied with the wavemeter to determine the unknown frequency.

When the unknown signal is relatively weak, such as the signal from a klystron oscillator, the wavemeter is usually used as an absorption type of device. Connection is made to the instrument at the input D. The RF loop C then acts as an injection loop to the cavity. When the cavity is tuned to the resonant frequency of the klystron, maximum energy is absorbed by the cavity and the meter dips, indicating a reduction of current. When the cavity is not tuned to the frequency of the klystron, high current is indicated on the current meter. Therefore, the cavity is tuned for a minimum reading, or dip, in the meter; and the resonant frequency is determined from the micrometer setting and the calibration chart.

Potentiometer R1 is used to adjust the sensitivity of the meter from the front panel of the instrument. J1 is a video jack and is provided for observing video waveforms with a test oscilloscope.

A directional antenna is used in conjunction with the instrument for making relative field strength measurements of radiated signals, for use in measuring the frequency of radar transmitters, and for constructing radiation patterns of transmitting antennas.

In radiation pattern measurements, the directional antenna is connected to the wavemeter input, and the instrument is tuned to the frequency of the system under test. The cavity is then locked on this frequency by an AFC system. The output signal being measured must be continuous and constant for reliable results. This is necessary in order for any variation in the meter reading to be caused directly by a change in the actual field strength of the signal when the position of the wavemeter is changed with respect to the transmitting antenna. After establishing a reference level on the meter, the position of the wavemeter is then changed by moving it around the radiating antenna, maintaining a fixed distance from it. The wavemeter readings at various positions around the transmitting equipment are recorded on polar graph paper, and the field pattern is thereby determined.

Counting Type

Frequency Meter AN/USM-26 is a precision instrument that automatically measures frequencies to 100 MHz and automatically displays its measurements in digital form on an 8-place panel indicating system. In addition to making direct measurements of frequency, the AN/USM-26 also measures period (time of one cycle of periodic wave), time intervals, and frequency ratios, and may be used to count random events such as those encountered in nuclear work. The equipment further includes a self-check feature that enables the operator to verify the proper operation of the equipment for most types of measurements.

By use of the Frequency Converter AN/USA-5 plug-in unit, the useful operating range of the USM-26 is extended to 220 MHz. Similarly, using the Transfer Oscillator CM-102/USM-73 in conjunction with the USA-5 further extends the frequency range to the vicinity of 5 GHz (gigahertz) before the harmonics become too weak for use. Use of a tunable detector allows the operator to resonate the signal to be measured, thus increasing the sensitivity of the equipment for detection of harmonics. This extends the upper limit of operation to about 12 GHz. A second tunable detector can be used to further increase the sensitivity by resonating the desired harmonic produced by the transfer oscillator.

Because of the accuracy with which it measures frequencies, the USM-26 equipment can be considered to be a new type of secondary frequency standard that replaces more elaborate installations of conventional precision frequency-measuring equipment. For example, the meter has been found particularly useful for frequency measurements in quartz crystal grinding work as well as for general laboratory quality frequency measurements. Other typical frequency-measuring applications for the equipment include calibration of transmitters, oscillators, signal generators, etc.

In combination with tachometer generators or other suitable transducers, the equipment can be used to make precision tachometry measurements. In tachometry work it is particularly useful for measuring the rotation frequency of high speed devices. When used in conjunction with a sensitive radioactivity detector and a suitable transducer, the USM-26 can provide an extremely accurate indication of the radio-activity radiation level.

Time measurements that the equipment will make include pulse length, pulse interval, time delay, etc.

Since the indicating system in the equipment presents the measured frequency in as many as eight significiant figures, the equipment is especially useful for measuring very small frequency changes such as are encountered when making measurements of frequency stability of oscillators and similar frequency generators.

COMPONENT TESTERS

This section discusses the testing of components considered to be most essential in any electronic circuit. These components include the transistor, crystal diode, and the electron tube. During the process of maintaining the equipment for which the technician is responsible, these three particular components are the ones with which he becomes most involved.

ELECTRON TUBE TESTER

Before discussing the testing of electron tubes on the tube tester, the substitution method of testing is described.

Substitution of a tube known to be good is a simple and reliable method of determining the quality of a questionable tube. Usually this method cannot be used to eliminate more than one tube in a single circuit. For instance, if both an RF amplifier and an IF amplifier are defective in a receiver, replacing either one does not correct the trouble. Also the practice of replacing several tubes in a circuit, all at one time, will usually result in misalinement of a tuned circuit. Under conditions such as these, the use of test equipment designed for testing the quality of a tube saves valuable time.

Experience has shown that tube failures may be roughly classified as follows: mechanical defects and gas within the tube, filament (or heater) burned out, change in tube characteristics, physical damage, and intermittent shorts. Mechanical defects and rise of gas pressure within the tubes are attributed to faulty construction and processing. Some of these defects cannot be detected by standard testing methods until the tubes have been in operation for some time. Filament burnout may be caused by repeated sudden application of full voltage to the filament. Initial heating of the filament is nonuniform. As a result, mechanical stresses due to thermal expansion are set up, and these stresses weaken the filament structure and hasten its failure.

Change in tube characteristics is a broad classification and covers decreasing emission, change in cutoff voltage, changing transconductance, etc. Such changes are usually the result of deterioration of the cathode structure, or formation of a cathode interface surface in the tube or changes in alinement of the electrode parts. Physical damage is largely accidental. It includes such causes as breakage, bending of pins, and inadvertent application of excessive voltages. Intermittent shorts are caused mainly by foreign matter, such as lint within the tube assembly.

Two common types of tube-testing equipment are the emission tube tester and the transconductance tube tester. These types may also incorporate circuits for making important tests other than emission and transconductance. Several types of tests are described in the following paragraphs.

Emission Tube Tester

The emission tester measures the condition of the cathode emitting surface. The end of the useful life of a tube is usually preceded by a reduction in electron emissivity, that is, the cathode becomes unable to supply the number of electrons necessary for proper tube operation. Also, if the tube has an open element, the defect prevents proper emission, and the tester indicates it as a reject. Both multigrid and diode tubes are tested for cathode emission.

The emission tester has certain limitations and disadvantages. Since the manufacturer of a tube does not state a definite 100 percent emission point which could be used for reference, the emission test is not conclusive. High emission does not necessarily indicate a good tube, because this condition might be present in a tube with a faulty grid structure or one which has a highly emissive spot on its cathode. Very high emission has also been observed just before a tube fails completely; hence, fairly low emission does not necessarily indicate in all cases that a tube is near its end-of-life point.

A further disadvantage of the emission test is that gas is liberated within the tube when a-c test voltages are applied unless the test is made quickly. Also, because the tube is not tested with its circuit d-c electrode voltages in this test, it is not tested under actual operating conditions. It is also possible for a tube to show normal emission and still not operate properly. The reason for this is that the efficiency of a tube depends on the ability of the grid voltage to control the plate current. The emission type tester tests only the plate current developed, and not the ability of the grid to control the plate current. The transconductance type tester checks the latter characteristic.

Transconductance Tube Tester

The term transconductance (also called mutual conductance) expresses the effect of grid voltage upon the plate current of a tube. By measuring the transconductance of a tube it is possible to evaluate the condition of the tube much more accurately than by measuring its cathode emission, because this test more closely approximates actual circuit conditions.

Transconductance is expressed mathematically as the ratio of a change in plate current to a change (small) in control-grid voltage with all other electrode voltages held constant. Transconductance is measured in units of conductance called micromhos. The equation for transconductance is:

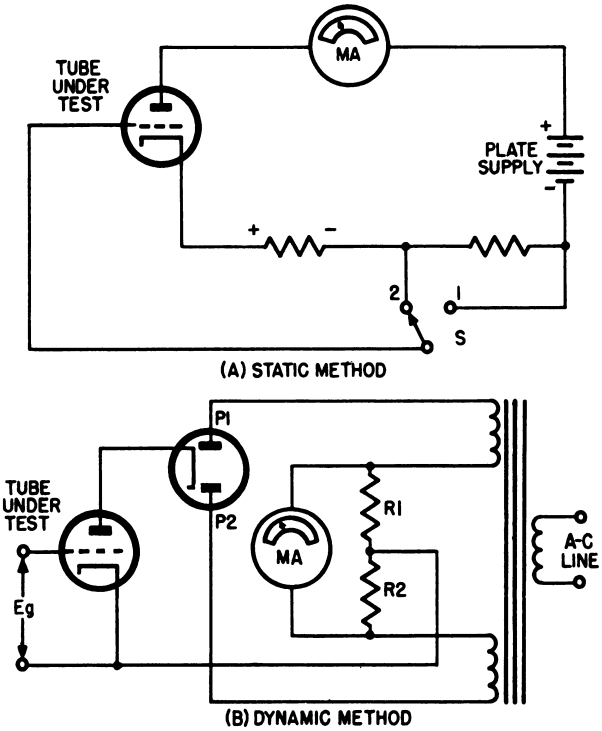
$$G_m = \frac{\Delta I_p}{\Delta E_g}$$

where G_m is the transconductance in micromhos, ΔIp is the change in plate current in microamperes, and ΔEg is the change in control-grid voltage. When the control-grid voltage changes 1 volt (positive or negative), the current change in microamperes is equal to the transconductance in micromhos. In other words, if an amplifier tube has a transconductance of 2,000 micromhos, a 1-volt change in the control-grid voltage will cause a plate-current change of 2,000 microamperes. The transconductance of a tube may be measured by two methods: one method is the static (d.c.) method and the other is the dynamic (a.c.) method.

STATIC METHOD.—In the static method (also called the "grid shift" method) of measuring transconductance, the d-c bias voltage on the control-grid of the tube under test is changed, and the resultant change in the steady plate current is measured with a current meter. The test circuit is shown in (A) of figure 8-17.

With switch S set to position 1, a negative bias voltage is applied to the control grid of the tube and causes a certain value of plate current to flow. When switch S is set to position 2, the control-grid voltage becomes less negative, and the plate current increases to a new value. If the control-grid voltage is varied by 1 volt, the transconductance is the difference (in microamperes) between the initial plate current reading and the new value of plate current. When such a circuit is used to test various types of tubes, the voltage applied to the electrodes must be made adjustable, so that the correct operating conditions for each tube type may be attained.

DYNAMIC METHOD.—The dynamic method of determining transconductance makes use of a circuit which applies an a-c signal to the control grid of the tube under test, in addition to a fixed (operating) control-grid bias. The basic circuit is shown in (B) of figure 8-17. The tube under test serves as the load for the rectifier circuit. The d-c milliameter is connected across a center-tapped resistor, the upper and lower parts of which are designated as R1 and R2. The meter and resistor combination is placed in series with two secondary windings of the a-c line-voltage transformer. With a fixed value of bias voltage (E_g) applied to the control grid of the tube under test, the circuit operates as a simple full-wave rectifier.



(A) STATIC METHOD

(B) DYNAMIC METHOD

AT.104

Figure 8-17.—Basic circuits used for transconductance test.

On the half-cycle of the a-c voltage when plate P1 of the double diode is positive, there is a current flow through R1, and the force exerted on the meter pointer attempts to deflect it in one direction. When the a-c voltage reverses and plate P2 is positive, the current flows through R2, and the force exerted on the meter pointer is equal and opposite to the pre-

Nomenclature for figure 8-18.

1. Fuse lamp.
2. Line adj. control.
3. Pilot light.
4. Power switch.
5. Filament voltage.
6. Filament selectors.
7. A-c line cord.
8. Grid jack.
9. Bias control.
10. Plate jack.
11. Shunt control.
12. Neon lamp.
13. Meter.
14. Meter reverse switch.
15. Rectifier switch.
16. OZ4 switch.
17. Gas 2 switch.
18. Gas 1 switch.
19. Mut. Cond. switch.
20. Diode switch.
21. Line adj. switch.
22. Function switch.
23. Suppressor selector.
24. Cathode selector.
25. Screen selector.
26. Plate selector.
27. Grid selector.
28. Power cord.
29. Test leads.
30. Pin straighteners.
31. Adapter.
32. Test data book.

vious force. Since these alternations occur at a rather rapid rate (60-hertz line voltage), the resultant force exerted on the meter pointer is zero; consequently, it remains stationary in the zero position.

Operation of a Typical Tube Tester

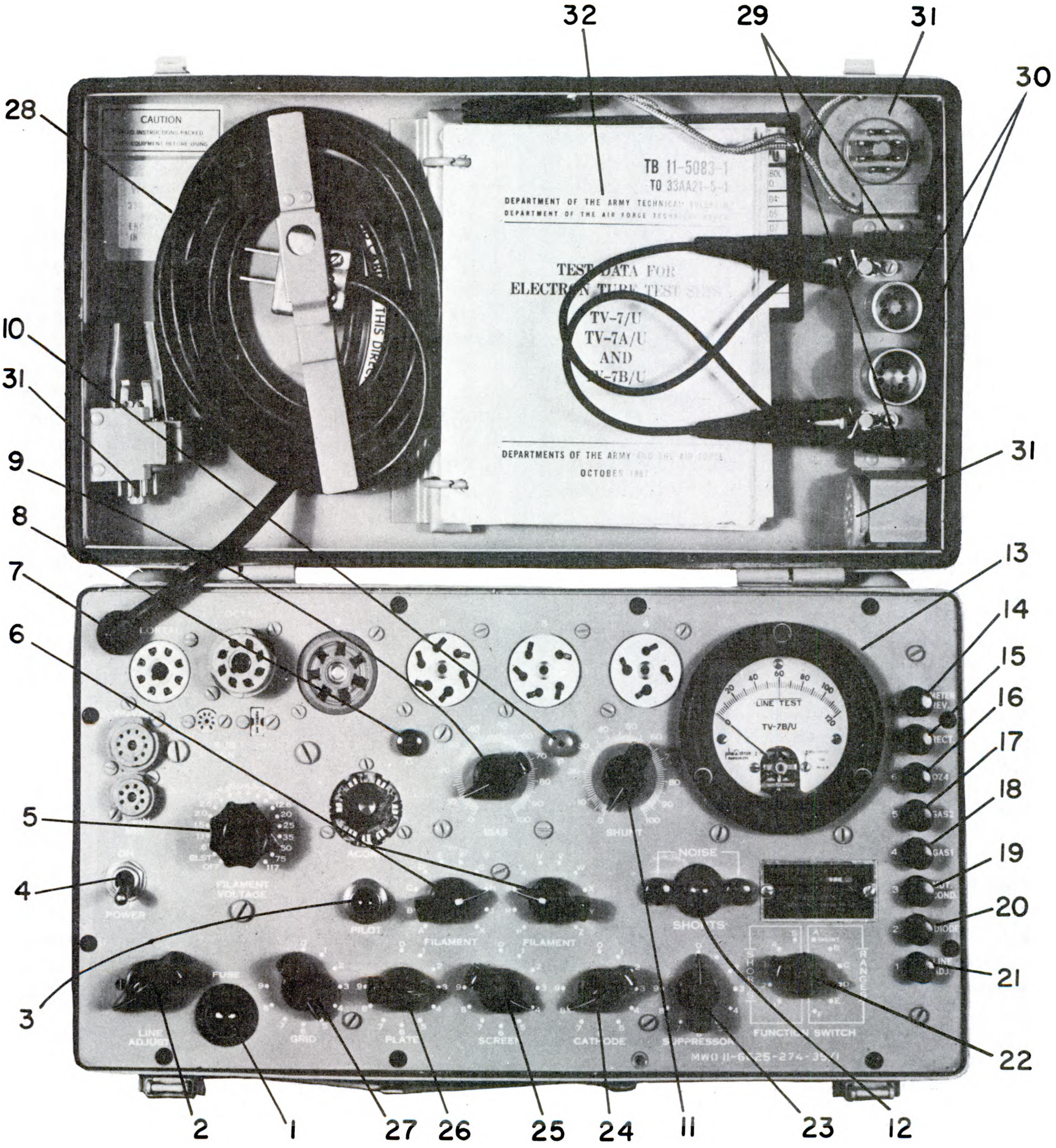
The tube-testing equipment discussed in this section is a typical, general-purpose test equipment of the transconductance type. The TV-7/U tube tester (fig. 8-18) is representative of this type equipment.

The front-panel controls on this tester adjust (or switch) the various potentials necessary for the testing of tubes. The tube data chart (booktype) which is supplied with the equipment, lists the control setting for the various types of tubes generally encountered in the field.

CAUTION: Before the tube to be tested is inserted in the correct test socket, make certain that the front-panel controls are set to the positions listed for that type tube in the data chart. This precaution is necessary to prevent excessive voltage from being applied to the tube elements (especially the filament).

LINE VOLTAGE ADJUSTMENT AND TEST.–The line voltage adjustment is necessary so that the line voltage applied to the primary of the transformer can be preset to an operating value. A 93-volt potential is used as a test reference point, regardless of the variations caused by different tube loads or fluctuations in the a-c supply. Applied voltages may range from 105 to 130 volts and still be adjustable. Depressing the LINE TEST button connects the meter of the tube tester to read the "B" supply voltage. The test equipment is calibrated at the factory so that the meter pointer is approximately centered when the voltage across the primary is 93 volts. Since various types of electron tubes draw different values of currents, a LINE ADJUSTMENT rheostat (connected in series with the primary) is provided. The primary voltage can thus be set to the designed operating voltage before any test is begun. A small protective lamp which will burn out on overload is connected in series with the primary of the transformer to prevent equipment damage.

SHORT CURCUIT AND NOISE TEST.–It is very important that the technician apply the test for short-circuited elements to a tube of doubtful quality before any other tests are made. This procedure protects the meter (or any other indicator) from damage. Also it follows logically that, if a tube under test has elements which are short-circuited, there is no further need to apply additional tests to that tube. Short-circuit tests are usually sensitive enough to indicate leakage resistance less than about one-fourth megohm. The proper heater voltage



AT.105

Figure 8-18.—Electron Tube Test Set TV-7/U.

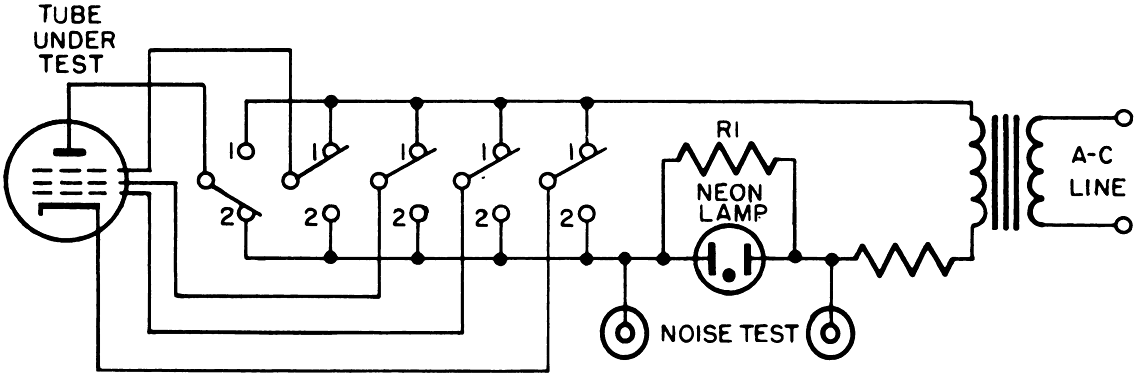
is applied so that any tube elements which might short as a result of the heating process will be detected. The short-circuit test is similar to the test used to detect noisy (microphonic) tubes caused by loose elements. Since the only difference between the two tests is in the sensitivity of the device used as an indicator, the noise test is discussed as part of the short-circuit test.

Figure 8-19 shows a basic circuit used for detecting shorted elements within a tube. With the switch set to position 2 as shown, the plate of the tube under test is connected to the leg of the transformer secondary containing the neon lamp. All the other elements are connected through switches to the other leg of the secondary. If the plate element of the tube is touching any other element within the tube, the a-c circuit of the secondary is completed and as a result, both plates of the neon lamp glow. If no short exists, only one plate of the neon lamp will glow. Each of the other elements is tested by means of the switching arrangement shown. Resistor R2 limits the current through the neon lamp to a safe value. Resistor R1 bypasses any small alternating currents in the circuit which might be caused by stray capacitance and thus prevents the neon lamp from indicating erroneously. Tapping the tube lightly is recommended to detect loose elements which might touch when the tube is vibrated.

In the test set shown in figure 8-18 the circuit used to test for shorts is similar to the basic circuit of figure 8-19. By means of the function switch the electrodes of the tube under test are switched in turn across a neon SHORTS lamp, which is connected in series with the secondary of the transformer. Shorted tube elements (and any other internal tube connections) complete the a-c circuit, causing both plates of the neon lamp to glow. Momentary flashes of the neon SHORTS lamp may be caused when the switch is rotated. These flashes are caused by the charging of the small inter-electrode capacitances of the tube when the voltage is applied, and do not indicate short circuits. If the tube under test has a shorted element, the neon lamp will glow continually on one or more switch positions. Since the filament circuit and other internal tube connections will show up as short circuits in this test, the tube data chart should be consulted for pin connection information before interpreting the results of the test.

The noise test is used to check for intermittent shorts or microphonic noise. The circuit used is the same as that employed for the short-circuit test. In tests for noise, the antenna and ground terminals of a radio receiver are connected to the NOISE TEST receptacles. Any intermittent short between tube electrodes permits the a-c voltage from the power transformer to be applied momentarily to the neon lamp.

The brief oscillation of this lamp contains various radiofrequencies which are reproduced as audible signals in the receiver speaker. A less sensitive noise test can be made using a pair of headphones instead of the radio receiver. The tube should be tapped while it is being tested.



AT.106

Figure 8-19.—Basic circuit used for short circuit and noise tests.

GAS TEST.—In all electron tubes, except some types of rectifier tubes and thyratrons, the presence of any appreciable amount of gas is extremely undesirable. When gas is present, the electrons emitted by the cathode collide with the molecules of gas. As a result of these collisions, electrons (secondarily emitted) are dislodged from the gas molecules, and positive gas ions are formed. These ions are attracted by (and cluster around) the control grid of the tube, because it is negative (bias) and absorbs electrons from the grid circuit in order to revert to the more stable gas molecules (not ionized). If the amount of gas in the tube is appreciable, the collisions between the numerous gas molecules and the cathode-emitted electrons release many secondarily emitted electrons, and the resulting flow of grid current is high.

The basic circuit used for the gas test is shown in figure 8-20. With switch S set to position 1, a certain value of plate current is measured by the d-c milliammeter. If there is no gas (or a negligible amount) present in the tube, setting switch S to position 2 does not change the plate-current reading. If gas is present, current flows through the grid resistor (large value), causing a voltage drop to develop with the polarity as shown. The net effect is to reduce the negative bias voltage on the grid of the tube resulting in an increase of plate current. Small plate current increases are normal; large increases indicate excessive gas.

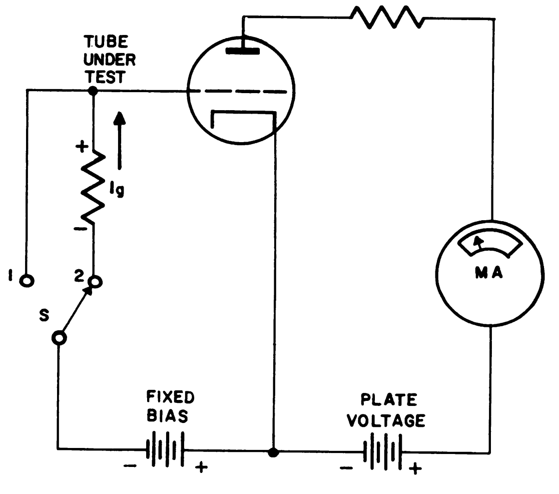


Figure 8-20.—Basic circuit used for gas test.

The value of the grid resistor used in the typical tube tester is 180,000 ohms. Two push-button switches, labeled GAS No. 1 and GAS No. 2, are used for gas test. GAS No. 1 button is first depressed and the plate current reading on the meter is noted. Depressing the button marked GAS No. 2 inserts the 180,000-ohm resistor into the grid circuit. If gas is present in the tube, the grid current that flows reduces the normal bias on the tube and increases the plate current measured by the meter. A tube with a negligible amount of gas produces an increase in plate current of less than one scale division when GAS No. 2 button is depressed. An increase of more than one scale division indicates an excessive amount of gas in the tube.

CATHODE LEAKAGE TEST.—The cathode element of an electron tube is essential because it supplies the electrons necessary for tube operation. Electrons are released from the cathode by means of some form of energy—generally heat—which is applied to it. An indirectly heated cathode consists of a heater wire (usually a tungsten alloy) enclosed in, but insulated from, a metal sleeve (nickel). This sleeve is coated with an electron emitting material (usually strontium or barium compounds) on its outer surface, and is heated by radiation and conduction from the heater. Useful emission does not take place from the heater wire.

When a tube which uses an indirectly heated cathode develops noise, it is almost a certain indication that a leakage path is present between the cathode sleeve and the heater wire. This assumption is justified because in the design of a tube the heater must be placed as close as possible to the cathode so that maximum tube efficiency is attained. Continual heating and cooling of the tube structure may cause small amounts of the insulation between the cathode and heater to become brittle or deteriorate, leaving a high resistance leakage path between these elements. Under extreme conditions the insulation may shift enough to allow actual contact of the elements. Since the heater and cathode are seldom at the same potential, any form of leakage causes noise to develop in the tube.

The cathode normally is maintained at a higher positive potential, because cathode bias is the most common type of bias utilized. The heater circuit is usually grounded to chassis, either on one side of the filament supply or by a center-tap arrangement. Therefore, if a resistance path is present, a leakage current may flow from the heater to the cathode. Thus, in effect the cathode functions in the same manner as the plate of a tube; that is, it receives electrons. Assuming the existence of a high-resistance short, the current flow from the heater to the cathode will vary with any vibration of the tube because vibration varies the amount of resistance. If the cathode and heater are completely shorted (zero ohms), it is impossible for the tube to develop any cathode bias.

A cathode leakage test is sometimes made while a tube is being tested for short-circuited elements or noise. However, some tube-testing instruments incorporate the cathode leakage test as an additional test which is not part of the short-circuit test. Figure 8-21 shows a basic circuit which is used to detect leakage between the heater and cathode elements of a tube. With switch S set to position 2, a certain value of plate current flows.

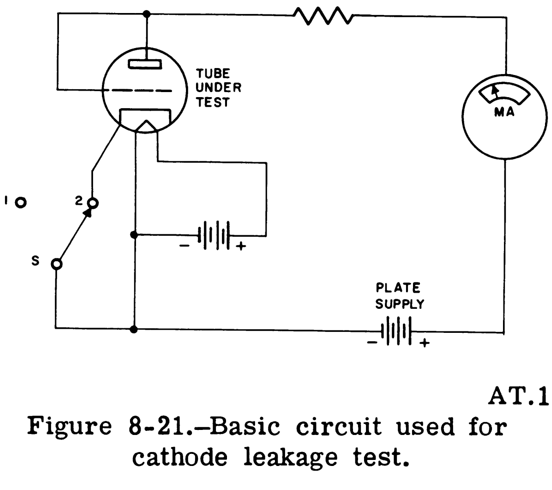
When switch S is set to position 1, the cathode becomes a floating element; if no leakage path is present, the plate current should fall to zero. If the elements are completely shorted, the plate current reading remains the same as the initial reading (switch S in position 2); if they are only partially shorted, a plate current less than normal but greater than zero is indicated.

FILAMENT ACTIVITY TEST.–The filament activity test is used to determine the approximate remaining life of an electron tube insofar as the longevity of the cathode emitter is concerned. The test is based on the principle that the cathode in almost all electron tubes is so constructed that a decrease of 10 percent of the rated heater voltage causes no appreciable decrease in emission.

On a tube-testing equipment incorporating this test there is a two-position switch (FILAMENT ACTIVITY TEST) which has one position marked NORMAL and the other marked TEST. The switch remains in the NORMAL position for all tests other than the filament activity test. When the switch is set to the TEST position, the filament (or heater) voltage which is applied to the tube under test is reduced by 10 percent.

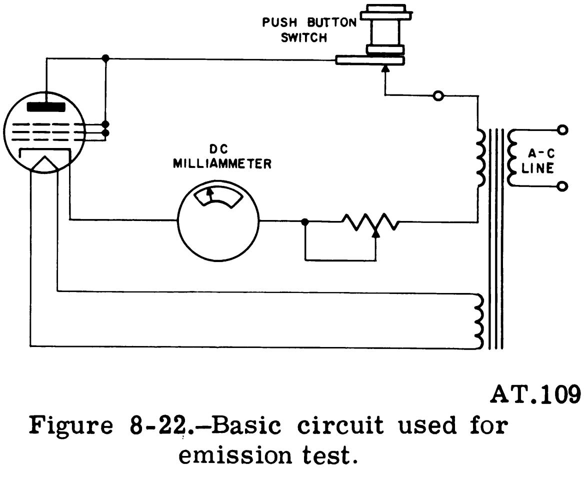
The filament activity test is performed as follows: After the quality test is made, the TUBE TEST button is held depressed, and the filament activity test switch is set to TEST position. If the indicator shows a decreased reading after a reasonable time is allowed for the cathode to cool, the useful life of the tube is nearing its end.

RECTIFIER TEST.–The circuit used for testing full-wave rectifiers, diodes, and 0Z4 tubes is an emission test circuit which is similar to the basic circuit shown in figure 8-22. An a-c voltage of definite value is applied to the tube under test, and the meter indicates the rectified plate current. The two sections of a full-wave rectifier are tested separately.



AT.108

Figure 8-21.–Basic circuit used for cathode leakage test.



AT.109

Figure 8-22.–Basic circuit used for emission test.

The button for testing OZ4 cold-cathode rectifier tubes provides a higher a-c voltage than is normally used for heater (or filament) type rectifiers. The button for diode tubes provides a lower voltage than that used for regular rectifiers, and also inserts a protective series resistance.

QUALITY TEST.—For the quality test, the d-c grid bias for the tube under test is supplied by a rectifier tube. The correct value of this grid bias is obtained when the bias control is rotated to the setting listed in the test data chart, for the tube being tested. An a-c voltage (4.7 volts rms), which is taken from a separate winding on the power transformer, is applied in series with the grid bias. This voltage causes the grid to deviate in positive and negative directions from the d-c bias level, thereby effecting the grid-voltage change (ΔE_g) required for a dynamic transconductance test. The plate voltage of the tube under test is supplied by a rectifier tube. The meter which indicates the plate current change (ΔI_p) is in the return circuit of the rectifier supply. The meter indicates the tube condition in arbitrary numerical units from 0 to 120. The tube test data book, mounted inside the cover of the equipment, lists the minimum numerical value of meter reading for satisfactory performance. Tubes reading below this value are not considered suitable for use in military equipment. The shunt control is used to control the sensitivity of the meter. Setting of the dial is required only when the function switch is in the RANGE (A) SHUNT position. The setting for this switch is determined by the type of tube being tested and is listed in the tube data chart. The operation of this circuit is the same as that of the basic circuit shown in part (B) of figure 8-17.

SEMICONDUCTOR TESTERS

Since semiconductors have replaced vacuum tubes in many new equipments, the testing of semiconductors has become increasingly vital. Two basic types of equipment are discussed in this section. They are the crystal diode tester and the in-circuit transistor tester, represented by the TS-1100/U.

Microwave Crystal Test Set

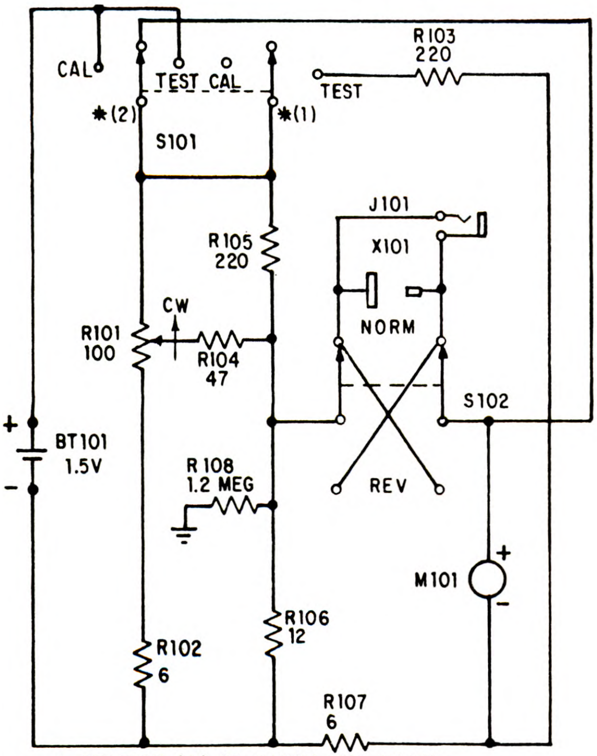
Microwave Crystal Test Set, Type 390 is used to provide an accurate and reliable indication of the quality of mixer crystals. Its accuracy is comparable to that of more elaborate laboratory test setups, but its testing versatility is more limited.

The quality of a microwave crystal can be determined by measurement of its conversion loss and noise temperature. The Type 390 is designed specifically to perform these tests on crystals intended for use at frequencies of 10,000 MHz and lower. For crystals used at frequencies above that figure, the readings are relative—crystals can still be selected in the order to comparative quality.

Conversion loss is defined as the ratio of the power available from the RF signal source to the power available at the IF output of the mixer. Noise temperature is defined as the ratio of the IF noise power available from the crystal to the thermal noise power available from a resistance (equal to the RF resistance of the crystal) at room temperature. The theory of the mixer crystal test set is based on the fact that the minimum conversion loss and noise temperature can be determined from the degree of nonlinearity of the static voltage-current (E-I) curve of a mixer crystal.

The Type 390 measures this nonlinearity by measuring the incremental change in crystal current (Δi) caused by an incremental change in voltage (Δe) applied to the crystal in the "forward" direction. Adjustment is made to the variable resistor R101 with the CAL-TEST switch in the CAL position. (See fig. 8-23.) If the E-I curve of the crystal under test were linear, a midscale reading would be obtained on meter M101 when S101 was switched to the TEST position. If the reading actually obtained is below midscale, the E-I curve of the crystal is nonlinear. The amount by which the reading falls below the midscale point is a measure of the degree of crystal's nonlinearity. The lower the meter reading below midscale, the more nonlinear the E-I curve for that crystal, and the lower its conversion loss and noise temperature.

Figure 8-23 is a schematic diagram of the test set. The initial adjustment of voltage V_i is made using variable resistor R101 with the



* SECTION (1) OF SWITCH S101 MAKES BEFORE SECTION (2)

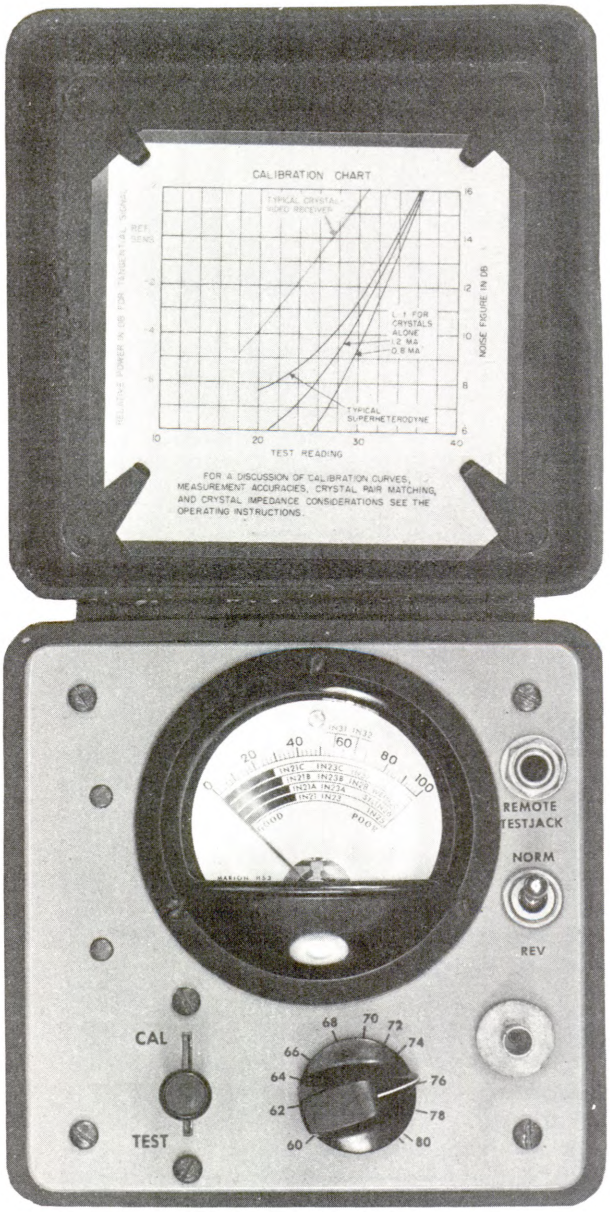
AT.110

Figure 8-23.–Microwave Crystal Test Set, Type 390, schematic diagram.

CAL-TEST switch S101 in the CAL position. (An incorrect adjustment of R101 may apply excessive voltage to M101, causing damage to the pointer. For this reason, R101 should always be set fully clockwise before switching to the CAL position). Also, see figure 8-24.

Fixed resistors R102, R104, R105, and R106 determine the limits to which V_i can be adjusted. The voltage increment (Δe) is established by R103 and R107 when in the TEST position; it has the same value for all crystals.

When a crystal is to be tested, it is placed in crystal holder X101. The crystal should always be handled by the base; while inserting the crystal, any static charge should be removed by touching the base to the grounding spring on the holder. The switch is set to the CAL position, and R101 is adjusted until the meter indication coincides with the calibration scale reading of R101. When S101 is moved to the TEST position, M101 indicates the quality of the crystal. With the aid of a chart supplied with the test set, the reading of M101 can be


CALIBRATION CHART
TYPICAL CRYSTAL VIDEO RECEIVER
TYPICAL SUPERHETERODYNE
TEST READING
NOISE FIGURE IN DB
10
20
30
40
FOR A DISCUSSION OF CALIBRATION CURVES, MEASUREMENT ACCURACIES, CRYSTAL PAIR MATCHING, AND CRYSTAL IMPEDANCE CONSIDERATIONS SEE THE OPERATING INSTRUCTIONS.
GOOD
POOR
0
20
40
60
80
100
REMOTE TESTJACK
NORM
REV
CAL
TEST
60
62
64
66
68
70
72
74
76
78
80

AT.111

Figure 8-24.–Type 390 microwave crystal checker.

converted to the actual conversion loss and noise temperature. Block sections on the meter scale help ease the acceptance or rejection of crystals according to the type being tested.

The purpose of the NORM/REV switch (S-102) is to provide the correct bias-voltage polarity for the crystal diode being tested; and to determine the polarity of a crystal diode when it is not known or when the crystal diode is located remotely from the test set.

In-Circuit Transistor Checkers

Test Set, Transistor TS-1100/U (fig. 8-25) is designed to measure the beta parameter of a transistor when the transistor is connected in a circuit, and to measure beta and I_{CO} parameters with the transistor removed from the circuit.

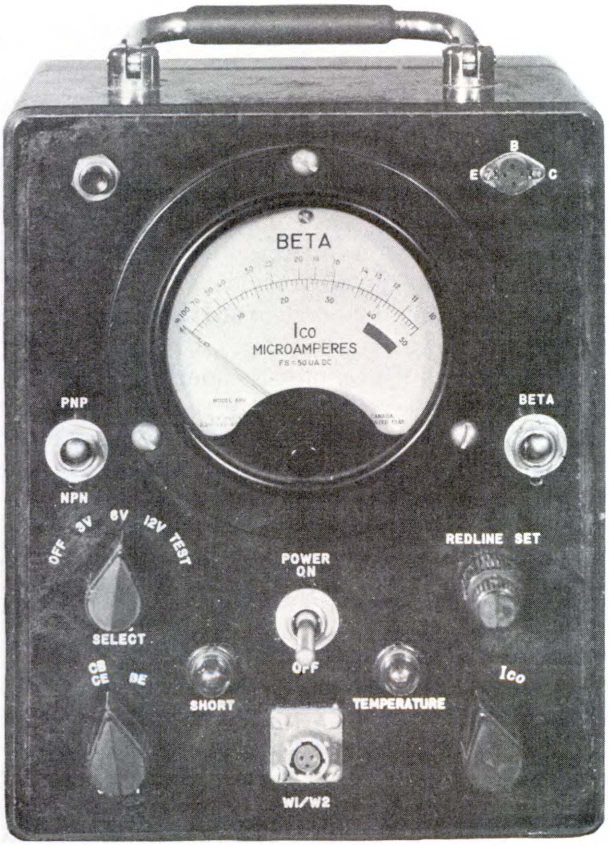


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Figure 8-25.—Test Set, Transistor TS-1100/U.

The characteristics of the test set are:

1. Range of beta 10 to ∞ in a single band.
2. Leakage current measurements: 0° to 50 microamperes.
3. Temperature range: 0° C to + 50 C.
4. Power Supply: Battery operated.

The equipment contains two separate battery power supplies. One provides the power for the internal circuits, and the other furnishes the bias voltage required for the transistor under test. Either the mercury type of zinc-carbon batteries may be used for operation of the test set.

Low impedance techniques are used for measurement to isolate the transistor under test from the surrounding circuitry. The measurement accuracy of the tester is within ±20 percent provided that the loading of the emitter-base diode or the collector-base diode is not below 500 ohms, and the loading between the collector and the emitter is not below 500 ohms. If the emitter-base load contains a diode, the series impedance should not fall below 7,000 ohms to maintain this accuracy.

With the use of an appropriate shorting technique, the accuracy can be improved. The shorting technique consists of connecting a jumper wire between the emitter of the transistor under test and the far side of all components connected to the base electrode of the transistor. This technique is not universally applicable, and it should be employed only by skilled personnel.

The range of beta that can be measured is between 10 and ∞. A beta of infinity (∞) corresponds to zero microamperes on the readout meter scale. A transistor having a beta below 10 will cause the pointer of the meter on the tester to move off the scale. Because of the nonlinear characteristic of the meter scale, which causes crowding at the high end, the readout accuracy for betas above 100 is impaired.

The following controls, as seen on the front panel (fig. 8-25), are incorporated in the test set:

1. POWER switch (labeled ON-OFF): Turns the internal power source on or off.
2. PNP-NPN (transistor select) switch: Selects proper collector bias polarity for the type transistor under test.
3. BETA switch: Permits readout of beta.
4. BIAS SELECT switch: Used to set proper collector bias voltages (nominally 3, 6, or 12

volts). Also checks the condition of internal battery when in the TEST position.

5. RED LINE SET control: Adjusts the amplitude of the test signal.

6. SHORT switch (labeled CB, CE, BE): Enables measurement of a short circuit or a low impedance in the collector-base (CB), collector-emitter (CE), or base-emitter (BE) circuits.

7. I_{CO} switch: Enables readout of transistor leakage.

8. SHORT indicator: The indicator lamp will light when a short circuit or low impedance exists in either the transistor under test or in the surrounding circuitry. If the lamp lights, this indicates a load of less than 500 ohms.

9. TEMPERATURE indicator: The indicator lamp will light when the ambient temperature surrounding the equipment exceeds +50° C. This indicates that the equipment is operating in an environment beyond that for which it has been designed, and that measurement inaccuracies will arise.

10. METER: Indicates magnitude of beta; indicates magnitude of I_{CO}; and indicates the condition of the internal battery. (The battery is good when the meter needle moves under the green band on the dial.)

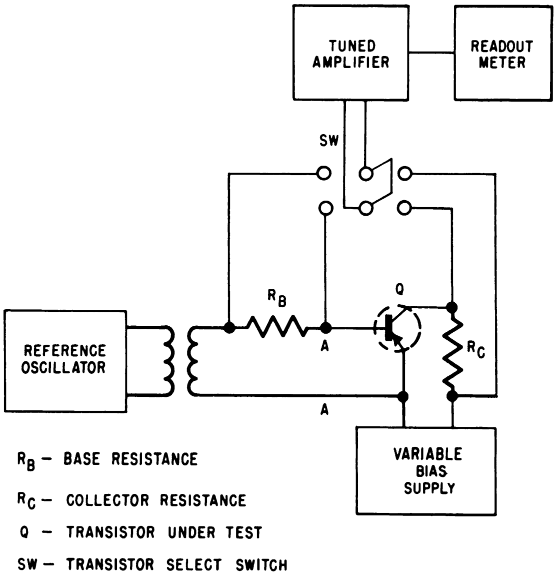
11. PROBE connector: For connecting the cables (furnished with the test set) to the transistor to be tested.

12. TRANSISTOR socket (labeled E-B-C): Enables direct connection between the test set and transistor to be tested.

13. BATTERY DISCONNECT switch (upper left corner of panel—not labeled): Disconnects the internal battery when the front cover is snapped in place.

For proper procedure in operating the test set, refer to Technical Manual for Test Set Transistor TS-1100/U, NavShips 93277.

FUNCTIONAL DESCRIPTION.—The block diagram (fig. 8-26) consists essentially of a reference oscillator, a tuned amplifier, and a variable bias supply. The oscillator is used to generate a test signal, the tuned amplifier is used to measure the second harmonic component of the current of the transistor under test, and the bias circuit furnishes the appropriate voltages to the transistor under test.



AT.113

Figure 8-26.—TS-1100/U, block diagram.

The reference signal source is a Hartley oscillator operating at a frequency of 1,125 Hz. The transistor under test is biased for approximately class B operation. Thus, the transistor conducts only when the input signal level exceeds the work function of the emitter-base diode. The input signal is adjusted until the average collector current is 1 milliampere. The current passes through the collector load resistor, and a voltage is developed across it. This signal is first coupled through a high gain, narrowband amplifier, having a center frequency of 2,250 Hz, and then through a d-c microammeter. The amplifier gain has been adjusted so that the red line on the meter face corresponds to an average collector current of 1 milliampere.

The bandpass amplifier and meter are then switched across the base load resistor, and the meter then reads the magnitude of the average beta directly for a given transistor. Since the collector current is held constant for all transistors under test, the base current is inversely proportional to beta.

Direct measurement of the average collector and base current cannot be made on a d-c meter placed in series with these electrodes. This is because of the large errors which may result from the presence of "sneak paths" provided by the external network, since it is possible to have a direct current flow in these paths from the collector bias supply.

By making an a-c measurement, the problems of erroneous direct current are eliminated, but others are introduced. If the a-c components of the collector current and base current were measured without filtering, the readout meter would not be able to differentiate between the normally rectified signal of the transistor and a nonrectified signal caused by the a-c sneak paths. To eliminate these erroneous signals, the second harmonic component of the signal current is measured.

TRANSISTOR CURVE TRACER (TEKTRONIX 575)

The Transistor Curve Tracer 575 is employed to plot or trace characteristic curves of transistors and other semiconductor devices. There are two different methods to plot the characteristic curves of a transistor. One is to apply d-c voltages and take measurements point-by-point. The other method is to use changing voltages and display the curve on an oscilloscope.

The 575 displays the curves by the use of the oscilloscope. There are several advantages in the use of the second method. To begin with, it is faster and more accurate than the point-by-point method. The point-by-point method may allow small irregularities in the characteristics to go undetected. Since heat is a major factor in transistor operation, errors caused by heat are reduced because the periods of applied power are shorter. Another definite advantage is that permanent records of the curves traced out on the oscilloscope may be easily produced at a reasonable cost by the use of photographic equipment.

This equipment is also provided with a self-calibration test. The operator can quickly reassure himself of the accuracy of the test set by the use of this built-in calibration check, in case a displayed curve deviates from the published nominal characteristic curve. The following paragraphs describe briefly how the 575 works and outlines a method for determining dial settings for transistors found in the fleet.

An illustration of the front panel of the equipment is shown in figure 8-27. As can be seen the controls are grouped into five blocks, with a test connector panel at the base of the test set. In addition to the block arrangement the panel is also color coded to simplify the operation. The collector currents and voltages are referenced by the sections of the panel etched in red; the sections etched in blue refer to the base currents and voltages. An exception to this color code is when a common base transistor configuration is being tested, at that time the blue is in reference to the emitter.

In the description of the five functional divisions that follows, refer to figure 8-27 for the item numbers listed; a functional block diagram is also given in figure 8-28.

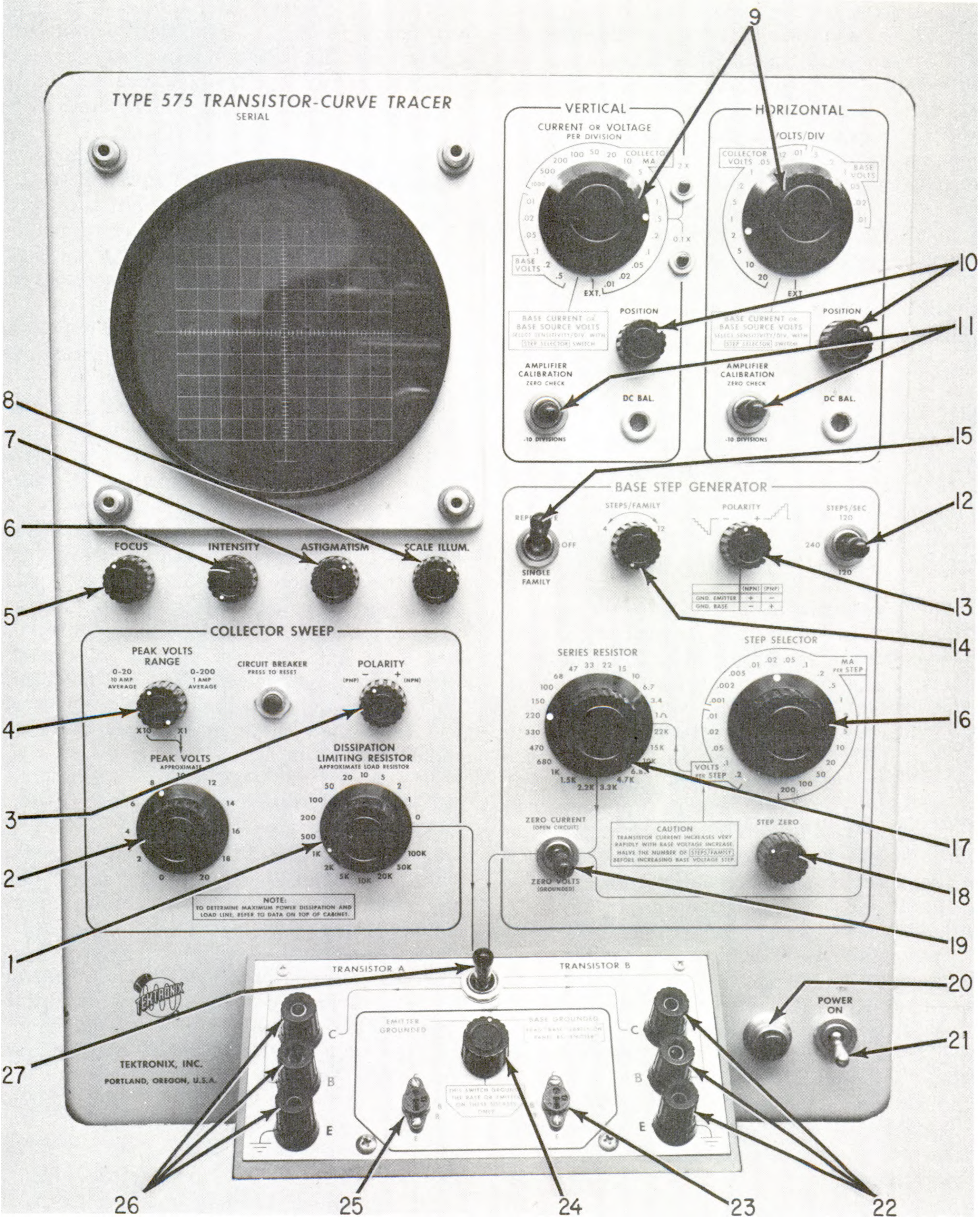
The collector sweep circuit supplies the transistor under test with a collector voltage which is the output of a full-wave rectifier without any filtering. The 60-Hz line voltage is supplied to the full-wave rectifier and the output of the rectifier is 120-Hz pulses. The output waveform varies from zero volts to some peak value which can be controlled from the front panel (items 2 and 4). The peak voltage can be varied in two ranges, from 0 to 20 volts and from 0 to 200 volts. The polarity of the sweep voltage can be reversed in order to check both PNP- and NPN-type transistors (item 3). A variable amount of resistance can be placed between the collector sweep supply and the transistor under test in order to limit the maximum amount of collector dissipation (item 1).

Base Step Generator

The step generator develops currents and voltages which change value in stairstep fashion in synchronization with the collector sweep voltage (items 12, 16, 17, and 18). The output of the generator can be reversed in polarity and can be connected to either the base or the emitter of the transistor under test (item 13). The number of steps can be varied from 4 to 12 according to the type of display desired (item 14).

Display Function

The display function includes the three major functional blocks remaining; the vertical and horizontal amplifiers, and the cathode-ray tube. (A description of the operation of a cathode-



AT.114

Figure 8-27.—Transistor curve tracer (Tektronix 575).

Nomenclature for figure 8-27.

1. Dissipation limiting resistor.
2. Peak volts control.
3. Polarity switch.
4. Peak volts range.
5. Focus control.
6. Intensity control.
7. Astigmatism control.
8. Scale illumination.
9. Vertical/horizontal select.
10. Display position.
11. Amplifier calibration.
12. Steps/sec selector.
13. Polarity switch.
14. Steps/family.
15. Repetitive/single family.
16. Step selector.
17. Series resistor.
18. Step zero.
19. Zero current/voltage.
20. Indicator lamp.
21. Power ON-OFF.
22. Binding posts B.
23. Socket B.
24. Configuration switch.
25. Socket A.
26. Binding posts A.
27. Comparison switch.

ray tube is given in Basic Electronics; an oscilloscope is also discussed later in this chapter.)

The horizontal and vertical amplifiers of the cathode-ray tube display can be driven by several different inputs, depending upon what characteristics are of interest (item 9). The horizontal amplifier can select any of four inputs and display one of them on the horizontal axis. The four inputs are base volts, collector volts, base current or base-source volts, and external. In the base volts position, the horizontal amplifier is connected to the base of the transistor under test. In the collector volt position, the horizontal amplifier is connected to the collector of the transistor under test. Both of these inputs have several positions so that the scaling factor can be changed. The base-current or base-source volts position connects the output of the base step generator into the horizontal amplifier. The external position connects the horizontal amplifier to two coax connectors on the rear of the instrument.

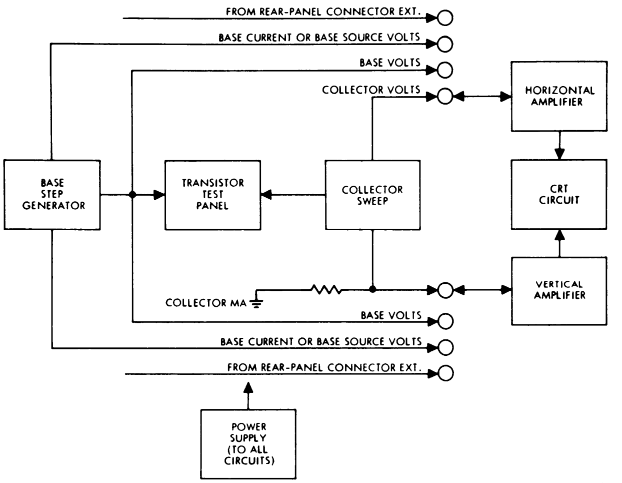

FROM REAR-PANEL CONNECTOR EXT.
BASE CURRENT OR BASE SOURCE VOLTS
BASE VOLTS
COLLECTOR VOLTS
HORIZONTAL AMPLIFIER
BASE STEP GENERATOR
TRANSISTOR TEST PANEL
COLLECTOR SWEEP
CRT CIRCUIT
COLLECTOR MA
VERTICAL AMPLIFIER
BASE VOLTS
BASE CURRENT OR BASE SOURCE VOLTS
FROM REAR-PANEL CONNECTOR EXT.
POWER SUPPLY (TO ALL CIRCUITS)

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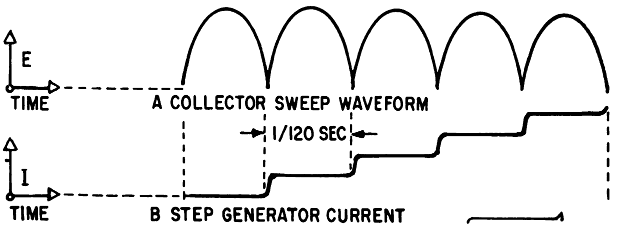
Figure 8-28.–Transistor curve tracer block diagram.

The vertical amplifier can also select from four different inputs: collector MA, base volts, base current or base-source volts, and external. Base volts, base current or base-source volts, and external positions are the same as described for the horizontal amplifier, but in the collector MA position, the vertical axis will give a plot of collector current.

INTERPRETING THE DISPLAY.–As the collector voltage changes from zero to some peak value and back to zero again, the step generator output remains at some specific level and then changes to some new level for the next collector voltage cycle. The collector voltage is swept at a rate of 120 Hz, and the step generator changes steps or level after every cycle (in the 240 steps per second, the step generator changes at both the zero point of the collector sweep and at the maximum point). Figure 8-29 is a plot of collector sweep voltage and base step generator current. It should be noted that the collector sweep makes a complete excursion, while the base is at some steady value. As the next collector sweep starts, the base current is changed to the next value of current selected by the dials on the front of the instrument, and again the base current will remain steady while the collector voltage is varied.



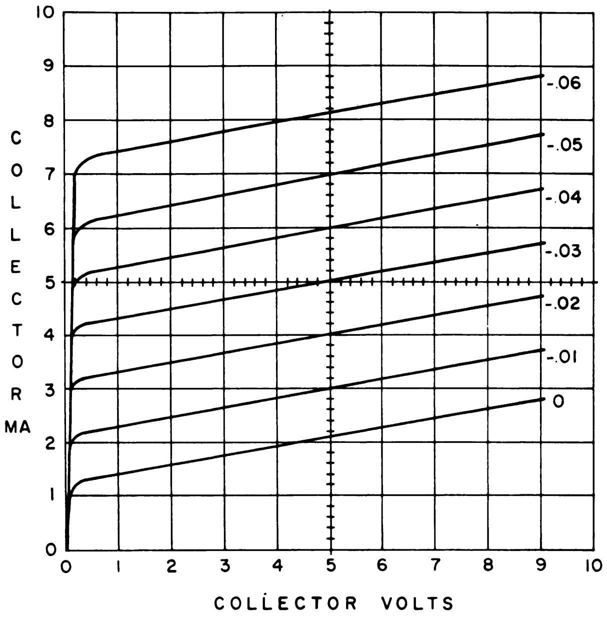
AT.116

Figure 8-29.–Waveforms of collector sweep versus step generator current.

As previously mentioned, the waveforms of figure 8-29 can be reversed by switches on the front panel in order to check either PNP or NPN.

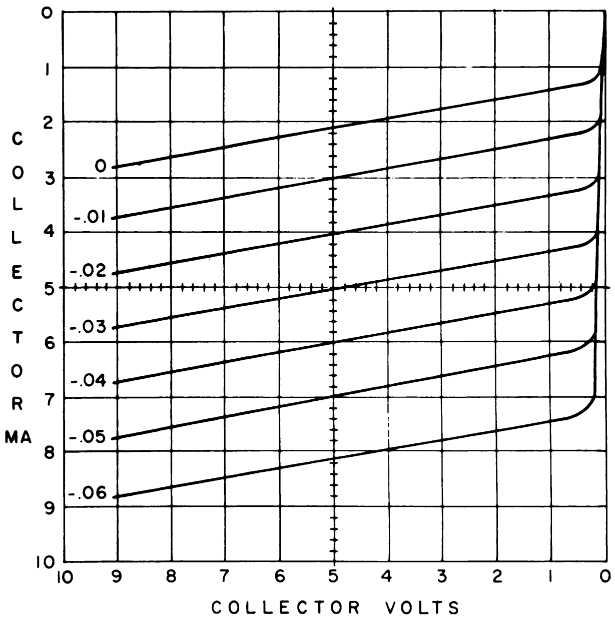
Figure 8-30 is a plot of collector voltage and collector current for given values of base current for an NPN transistor. For this type of transistor, it is a convention to have the lower left-hand corner represent zero collector voltage and current. In this graph, it was arbitrarily decided that each division to the right of the lower left-hand corner of the horizontal axis would represent a collector voltage change of one more volt positive. This would indicate a collector voltage swing of zero to 10 volts positive. The vertical axis is a plot of collector current varying from zero milliamperes in the lower left-hand corner to 10 milliamperes at the top of the graph in 1 milliampere steps. The different lines on the graph represent different values of base current; in this case, each line represents a change of 0.01 milliampere. If this graph had been for a PNP rather than for an NPN, the upper right-hand corner would have represented zero collector voltage and zero collector current. The divisions to the left would have represented negative collector voltage and the divisions downward from the top would have indicated the amount of negative current. This would have made the family of curves to appear as shown in figure 8-31.

These curves are known as the static collector characteristics for a common emitter configuration or output characteristics curve. Curves can be developed for common base and common collector also, but normally the information is available for the common emitter mode. Using this configuration, it is easier to check the transistor. To thoroughly describe how a transistor is going to work in a circuit,



AT.117

Figure 8-30.–Typical NPN collector curves.



AT.118

Figure 8-31.–Typical PNP collector curves.

it is necessary to know the input characteristic curve as well as the output curve. The input characteristic curve is developed by plotting base current on the horizontal axis, base to emitter voltage (V_{RE}) on the vertical axis at different values of collector to emitter voltage (V_{CE}). Although it is necessary for the design engineer to know the input characteristic curve when designing a circuit, the output characteristic curve will normally give the maintenance technician enough information to allow him to evaluate a transistor.

Measuring Beta (h_{fe})

One means of measuring the quality of a transistor is the Beta (β) or current gain in the common emitter configuration. Mathematically, Beta is represented by the formula

$$\beta = \frac{\Delta ic}{\Delta ib}$$

where V_{CE} is constant. Beta is also called the forward current transfer ratio and represented by the symbol h_{fe}, which is derived from the hybrid equivalent circuit of a transistor. To determine the Beta from the output characteristics, measure the change in collector current between two values of base current at some constant collector voltage; for instance, in figure 8-30, to determine the Beta at a collector voltage of 5 volts, measure the change in collector current between the base current curves of 0.02 ma and 0.03 ma. In this example, the change in collector current measures 1 ma, so the Beta is equal to the change in collector current divided by the change in base current or

$$\frac{1 \times 10^{-3}}{0.01 \times 10^{-3}} = 100$$

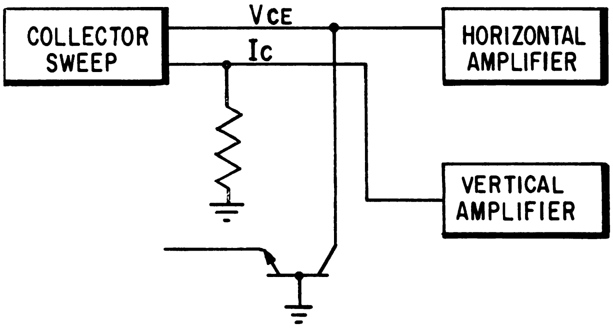
Measuring I_{CO}

Another characteristic of a transistor is the I_{CO}, also called I_{CBO}. This is the collector current when the collector is biased in the reverse direction (high resistance, normal connection) with respect to the base, and the emitter is open-circuited. The I_{CO} of a transistor is highly temperature-dependent and the measurement made with the curve tracer will be at the ambient temperature only; but it is still significant. The method used to measure the I_{CO} is shown schematically in figure 8-32. Notice that the emitter is not connected.

The display of the curve tracer when measuring I_{CO} is shown in figure 8-33. The vertical axis indicates collector current, just as it did when Beta was being measured; but now the vertical amplifier is adjusted to afford maximum gain so that the small amount of current causes a noticeable deflection. The horizontal axis is still calibrated to show collector voltage.

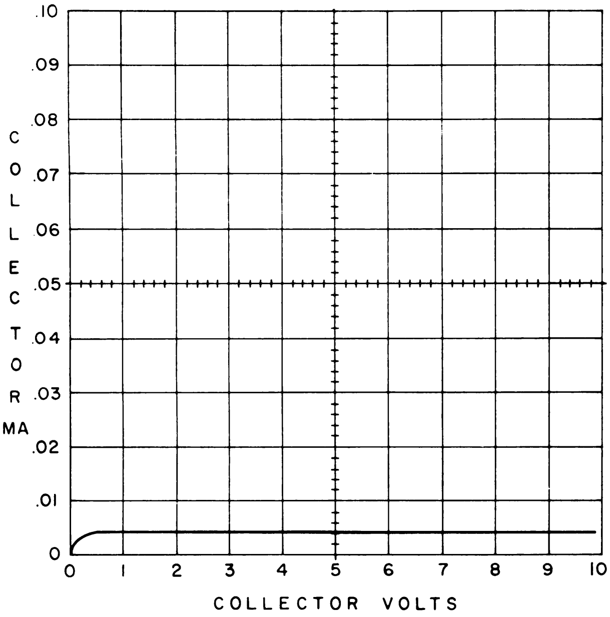
The technician must know the Beta and I_{CO} of a transistor in order to tell whether or not the one he is testing is good. Since no manual describing the characteristics of different transistors is provided with the curve tracer, it is necessary to obtain this information from other sources. NavWeps 16-1-530 Replacement Guide, Semiconductor Device (Transistors and Semiconductor Diodes), dated May 1963, is an excellent source. For those transistors not listed in this publication, a specification sheet can be obtained from the manufacturer.

Section 1A of NavWeps 16-1-530 is a list of transistor replacements. Section 1A also gives the technical section in which a specific transistor is listed. These are Sections 2 through 10. To use this manual, look up the transistor in the technical section which applies; descriptions at the top of each page tell whether the transistor is germanium or silicon, PNP or NPN, low or high power. The important columns



AT.119

Figure 8-32.—Connections for checking $I_{CO}(I_{CBO})$.



AT.120

Figure 8-33.–Typical display of $I_{CO}(I_{CBO})$.

in the technical section needed to obtain information on testing are MAXIMUM COLLECTOR DISSIPATION, ABSOLUTE MAX RATINGS, MAX I_{CBO} at MAX V_{CB}, Typical "h" Parameters at 25° C.

Under the column labeled Typical "h" Parameters, there is listed a typical h_{fe} or a minimum and maximum value of h_{fe} depending on which technical section the transistor is listed in. In the same column is listed the collector voltage and collector current at which this h_{fe} is to be obtained.

The collector voltage (V_{CE}) and collector current (I_C) provide the starting points from which to determine the curve tracer settings; for instance, if the V_{CE} is 5 volts, the horizontal amplifier would be set to COLLECT or VOLTS, 1 volt per division. This would place the 5-volt position in the middle of the display, and if the I_C is 1-ma, the vertical amplifier would be set to COLLECT or MA, 0.2 MA per division. This would place the 1-ma position in the middle of the display. The collector sweep can be determined from these settings, since the horizontal amplifier is set to 1 volt per division. The collector voltage varies a total of 10 volts, so the PEAK VOLTS RANGE is in the 0 - 20 position and the PEAK VOLTS control is set at 10. To determine the setting for the DISSIPATION LIMITING RESISTOR, obtain the maximum collector dissipation from the column in the technical section labeled MAX COLL DISS. This, in conjunction with the setting of the PEAK VOLTS control, can be plotted on the chart on top of the curve tracer to obtain the correct setting of the limiting resistor.

The step generator is set up in the following manner. The switch labeled REPETITIVE-OFF-SINGLE FAMILY is set to REPETITIVE, and the control labeled STEPS/FAMILY is set counterclockwise. This gives four steps per family, which is usually sufficient; but if more are desired, set STEPS/FAMILY to any value. The switch labeled POLARITY has a chart under it showing the correct position for NPN and PNP. Use the portion of the chart pertaining to grounded emitter-type circuits. The switch labeled STEPS/SEC can be in either of the two 120 positions or in the 240. The only difference in the two 120 positions is that at one of them, the step generator changes level when the collector is at zero volts; and at the other position, the step generator changes level when the collector is at the maximum voltage. In the 240 position, the step generator changes level at both the zero collector voltage and at the maximum point. The step selector can be set by starting at the smallest change per step (0.001 ma) and increasing the size of the step until the display has the necessary separation between the values of base current to determine Beta. In the alternative procedure, the Beta listed in the technical section can be divided into the amount of collector current and the result used as the setting of the step selector. If there isn't enough separation between the lines representing the base current to accurately determine the Beta, increase the amount of each base step until a good display is obtained.

To check the I_{CO} of the transistor, disconnect the emitter and change the current per division setting on the vertical amplifier to the most sensitive position (0.01 ma). Set the step zero very accurately, as described in NA 16-45-107, which is the Service Instruction Manual and Operating Instruction Manual for the curve tracer. After setting the step zero, note the difference between the step zero and the present position of the trace; this is an indication of the I_{CO}. The I_{CO} of the transistor is listed in the technical section, in the column MAX I_{CBO} at MAX V_{CB}, which describes the I_{CO} at BV_{CBO}–the breakdown voltage, collector-to-base with emitter open.

By measuring Beta (h_{fe}) and I_{CO} (I_{CBO}), a fair picture of the condition of a transistor is presented. There is one thing that should be mentioned in connection with the curve tracer, however; matching of transistors. Some Navy equipments have matched pairs of transistors, but unless the specifications are checked, it cannot be automatically assumed that Betas of the transistors are matched. Sometimes the Betas are matched, sometimes they are not; many times several characteristics are matched.

SIGNAL GENERATORS

The principal function of a signal generator is the production of signals having the specific characterstics required for the test or measurement in question. It is very important that the amplitude of the generated signal be correct. In many generators, output meters are included in the equipment so that the output may be adjusted and maintained at a standard level over a wide range of frequencies.

When using the generator, the test equipment output signal is coupled into the circuit being tested. Its progress through the equipment may then be traced by the use of high impedance indicating devices such as vacuum tube voltmeters or oscilloscopes. In many signal generators, attenuators are provided. These are used to regulate the voltage of the output signal and also provide correct impedance values for matching the input impedance of the circuit under test. Accurately calibrated attenuators are desirable since the signal strength must be regulated to avoid overloading the circuit receiving the signal.

There are many types of sinusoidal signal generators. It is possible to classify them roughly by frequency into audio generators, generators of both the audio and video ranges, radiofrequency generators, frequency-modulated RF generators, and special types which combine all of these frequency ranges.

In addition, signals other than sinusoidal are also generated for testing of equipment. The signal generators producing nonsinusoidal outputs are usually classified according to the type of signals they produce. Some signal generators produce several types of signal waveforms.

In almost all currently used types of signal generators, electron tube oscillators are used to produce the initial signal. In order to achieve accurate results in the use of the signal source, it is necessary to allow the oscillator circuits to reach a condition of stable operation before applying the output. This condition is reached when the tubes and circuit elements attain the temperature at which the instrument was calibrated.

A preliminary warmup should always be given the generator when accurate and stable signals are desired. The minimum warmup time for the generator is contained in the Service Instruction Manual for each model. The general properties and functions of signal generators are covered in Basic Electronics. In the sections immediately following, there is a discussion of several types of generators.

In testing the receiver section of a transceiver, the output of the signal generator is usually connected to the antenna terminal of the transceiver. If the transceiver is then keyed, damage to the signal generator results. This damage usually includes burning out of the resistive elements of the signal generator output circuits; these elements are rated only for the comparatively low power of the signal generator. In this type testing configuration, it is essential that some form of protection be given the test equipment.

One form of protection which can be provided is a fuse in series between the signal generator output terminal and the transceiver antenna terminal. The value of the fuse is dictated by the output limitations of the signal generator–usually about 1/16 ampere is recommended.

SINE WAVE GENERATORS

Sine wave generators will be discussed under the heading of three classes. These classes are audio, video, and radiofrequency. The sine wave generator is used to produce simulated conditions for the alinement and testing of equipments.

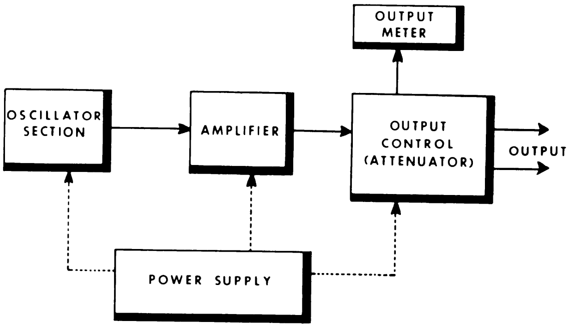
Audio and Video

Audio signal generators produce stable audiofrequency signals used for testing audio equipment. Video signal generators produce signals which include the audio range and extend considerably further into the RF range. These generators are used in testing video amplifiers and other wideband circuits. In both audio and video generators, the major components include a power supply, an oscillator (or oscillators), one or more amplifiers, and an output control. Voltage regulation circuits are necessary to insure stability of the oscillator in generators which derive power from 115-volt, a-c sources. In portable generators, battery power supplies are usually used, and these require no voltage regulation.

In the audio and video generators of the beat-frequency type, the output frequency is produced by mixing the signals of two radiofrequency oscillators, one of which is fixed in frequency and the other variable. The difference in frequency of the two is equal to the desired audio or video frequency. For example, if the fixed and variable oscillators both produce a frequency of 400 kHz, the resultant output frequency is zero. If the variable oscillator is changed to 401 kHz, the resultant is then 1 kHz. By action of this type, any desired frequency in the range of the circuits may be produced in the output.

Audio signal generators often include RC oscillators in which the audio frequency is directly produced. In these, a resistance-capacitance circuit is the frequency determining part of the oscillator. The frequency varies when either the resistance or the capacitance is changed in value. In commercial generators, however, the capacitance alone is often chosen as the variable element. The change in frequency which can be produced by this method is limited, and it is usually necessary to cover the entire range of the generator in steps. This is accomplished by providing several RC circuits, each corresponding to a portion of the entire range of frequency values. The RC circuits in the oscillator are switched to cover the desired portion of the audio range.

The amplifier section of the block diagram of figure 8-34 usually consists of a voltage amplifier and one or two power amplifiers. These are coupled by means of RC networks, and the output of the final power amplifier is often coupled to the attenuator, or output control, by means of an output transformer.



AT.121

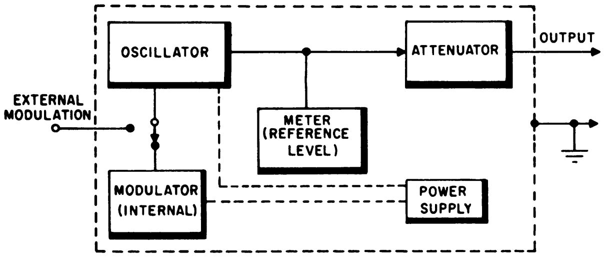
Figure 8-34.–Block diagram of typical audio or video signal generator.

The output control section provides a means of matching the output signal to the input of the equipment under test and regulating the amplitude of the signal. The settings of the output control knob provide output voltage values which are either inscribed directly on the knob or which can be interpreted by reference to the instruction manual provided with the generator.

Radiofrequency

A typical radiofrequency signal generator contains, in addition to the necessary power supply, three main sections–an oscillator circuit, a modulator, and an output control circuit. The internal modulator modulates the radiofrequency signal of the oscillator. In addition, most RF generators are provided with connections through which an external source of modulation of any desired waveform may be applied to the generated signal. Metal shielding surrounds the unit to prevent the entrance of signals from the oscillator into the circuit under test by means other than through the output circuit of the generator.

A block diagram of a typical RF signal generator is shown in figure 8-35. The function of the oscillator stage is to produce a signal which can be accurately set in frequency at any point in the range of the generator. The type of oscillator circuit used depends on the range of frequencies for which the generator



AT.122

Figure 8-35.—Block diagram of a radiofrequency signal generator.

is designed. In low frequency signal generators, the resonating circuit consists of one of a group of coils combined with a variable capacitor. One of the coils is selected with a range selector switch which attaches it to the capacitor to provide an LC circuit which has the correct range of resonant frequencies.

In signal generators designed for the higher frequencies, the resonating circuits are usually in the form of butterfly tuning circuits and resonant cavities. Reflex klystron oscillators are often used in generators of frequencies above 1000 MHz.

In any signal generator, it is required that the oscillators have good stability both in frequency and amplitude over a wide range of output frequencies.

The function of the modulating circuit is the production of an audio (or video) voltage which can be superimposed on the RF signal produced by the oscillator. The modulating signal may be provided by an audio oscillator within the generator (internal modulation), or it may be derived from an external source. In some signal generators, either of these methods of modulation may be employed. In addition, a means of disabling the modulator section is used whereby the pure unmodulated signal from the oscillator can be used when it is desired.

The type of modulation used depends on the application of the particular signal generator. The modulating voltage may be either a sine wave, a square wave, or pulses of varying duration. In some specialized generators, provision is made for pulse modulation in which the RF signal can be pulsed over a wide range of repetition rates and at various pulse widths.

Usually the output circuit of the generator contains a calibrated attenuator and often an output level meter. The output level meter gives an indication of, and permits control of, the output voltage of the generator by indicating arbitrary values of output read in tenths through the value of one.

The attenuator selects the amount of this output. The attenuator, a group of resistors forming a voltage-dropping circuit, is controlled by a knob which is often calibrated in microvolts. When the control element is adjusted so that the output meter reads unity (1.0), the reading on the attenuator knob gives the exact value (no multiplication factor) of the output in microvolts.

If output voltage is desired at a lower value, the control is varied until the meter indicates some decimal value less than one; this decimal is multiplied by the attenuator reading to give the output in microvolts.

SG-85/URM-25D.—RF Signal Generator Set AN/URM-25D is typical of most RF signal generators in common usage. It consists of Signal Generator SG-85/URM-25D, its case, and an assortment of accessory items.

It is intended primarily for bench testing of electronic equipment, covering the frequency range from 10 kHz to 50,000 kHz. This frequency coverage is accomplished in eight bands, and the RF output can be either modulated or unmodulated. The frequency generated can be read from a main frequency scale within an accuracy of ±0.5 percent; and by proper use of a 1-MHz internal crystal calibrator, the accuracy can be increased to 0.05 percent above 1 MHz.

This test set also generates an audio signal of 400 or 1000 hertz, which is used to modulate the RF carrier. The audio signals are also separately available at the front panel.

Operational procedure, technical characteristics, and theory of the SG-85/URM-25D can be found in NavShips 92134(A).

FM SIGNAL GENERATORS.—Frequency-modulated RF signal generators are widely used for testing frequency-modulated receivers and for visual alinement (using an oscilloscope) of AM receivers. A frequency-modulated signal is an alternating voltage in which the frequency varies above and below a given center frequency value. The overall frequency change is called the frequency swing.

There are several methods by which the frequency of the oscillator in the signal generator may be frequency modulated. In one type of FM generator, use is made of a vibrating plate which forms one of the elements of the tuning capacitor of the oscillator to be modulated. The plate is driven by a device similar to a magnetic loudspeaker. The audio modulating voltage is applied to the driving coil which moves in the field of a permanent magnet and vibrates the plate of the capacitor at the applied audiofrequency. Movement of the plate causes variation of the capacitance in the oscillator tuning circuit with the result that the frequency of the oscillator is periodically raised or lowered.

Another method of producing frequency modulation is based on the action of a reactance tube which is connected in parallel with the tuning circuit of the oscillator to be modulated. A reactance tube is an electron tube in which the plate current is made either to lead or to lag the plate voltage variations by 90°. Because of this phase difference, the plate circuit of the tube is electrically equivalent either to a capacitor or to an inductance. The modulating voltage is impressed on the grid of the reactance tube, causing the capacitive (or inductive) reactance of the plate circuit of the tube to vary. Since the reactance tube plate circuit is a part of the oscillator tuning circuit, variation in the reactance value causes the generated frequency to vary in step with the modulating voltage.

In signal generators of microwave frequencies, frequency modulation is easily accomplished in the oscillator by applying the modulating voltage to the repeller plate of the reflex klystron tube which is usually employed in these generators.

SWEEP GENERATOR AN/URM-75

Sweep Generator AN/URM-75 is a versatile precision test instrument used for alining and checking radio receivers in the frequency range of 5 to 220 MHz. Its major component is the SG-93/URM-75 sweep generator, which supplies signals for the following functions:

1. Observing frequency response, relative gain, and bandpass characteristics of RF, IF, and video stages.
2. Alining RF and IF circuits.
3. Checking and adjusting discriminators.
4. Determining relative receiver sensitivity.

Basically, the unit consists of an FM sweep oscillator, a marker oscillator, a crystal oscillator, an audio oscillator, a frequency converter, a blanking circuit, and two output jacks.

The FM sweep oscillator is tunable over a frequency range of 50 to 220 MHz. In conjunction with the sweep converter stage, the oscillator produces a sweep signal which is variable from 5 to 220 MHz. This extended range is covered in two bands.

On band B, the sweep converter is disabled and the sweep oscillator operates alone to cover the range of 50 to 220 MHz. On band A, the sweep oscillator signal is beat against a 116.5 MHz signal from a fixed frequency oscillator in the converter stage. This beat produces a signal which is variable from 5 to 50 MHz. The sweep output is available at the MIXED OUTPUT jack. The signal may be used alone or in conjunction with a marker signal.

The marker oscillator operates over a frequency range of 4 to 220 MHz, covered in 6 bands. The marker signal, either modulated or unmodulated, is then supplied to both the MKR OUT jack and the MIXED OUTPUT jack. By means of this signal, the exact frequency may be determined for any point along a frequency response curve produced by the sweep signal.

The crystal oscillator is normally operated at a fundamental frequency of 10 MHz. By insertion of the appropriate crystal, however, oscillation may occur between 4 and 15 MHz. The crystal oscillator output, either modulated or unmodulated, is supplied to both output jacks. This signal provides a means of correctly calibrating the marker oscillator, or of calibrating external signals.

The audio oscillator generates a signal of 600 Hz which may be used to modulate the marker output and/or the crystal oscillator output, if desired. It is not available as a separate output.

The generator incorporates an optional blanking circuit which produces a 60-Hz sine wave. The positive half of the sine wave is eliminated, and the negative half is applied to the grid of the FM sweep oscillator. This input cuts off the FM sweep during the period of the half cycle. Thus, when the operator activates the blanking circuit, the FM sweep oscillator produces pulses of energy occurring at a 60-Hz rate.

PULSE GENERATOR AN/URM-44A

The generation of pulse signals involves many fundamental electronic circuits and some special purpose tubes. Some of the circuits involved are multivibrators, limiters, clampers, discriminators, oscillators, and sawtooth generators. One of the special purpose vacuum tubes is the reflex klystron, which is used as an oscillator.

The TS-622A/U is a typical pulse generator. It is the main component of Radio Test Set AN/URM-44A.

The TS-622 is a signal generator of low power output and is used in the maintenance of radio and radar equipment operating in the frequency range between 7,000 and 10,750 MHz. It produces continuous-wave, pulse-modulated, and frequency-modulated signals. The output frequency and power level of the test set are indicated on separate direct reading dials located on the front panel.

In the pulse-modulated mode of operation, pulse widths of 0.5 to 10 microseconds may be obtained, and the pulse repetition may be adjusted from 40 to 4,000 pulses per second. Pulse modulation is obtained from a multivibrator which produces square waves of the above mentioned pulse widths and frequency.

In the frequency-modulated mode of operation, a sawtooth generator supplies a sawtooth of voltage to the reflex klystron to cause the signal to be frequency modulated.

In the CW mode of operation, the klystron is permitted to free-run at the frequency selected.

This test set includes an internal synchronizing generator (the multivibrator), and has provision for applying an external synchronizing signal of either positive or negative polarity. It also has provision for an external modulating signal to be applied.

The front panel provides the following three outputs:

1. The RF output, which is the output from the klystron oscillator.
2. An undelayed sync (undelayed synchronizing voltage).
3. A delayed sync. The syncs are either the output from the internal sync generator or an input from the external sync source.

The Service Instruction Manual, AN 16-30URM44-2, contains a breakdown of all circuits of the test set and detailed theory of operation of each. Also included in the manual is a master block diagram to simplify the explanations.

PULSE GENERATOR AN/UPM-55

This equipment is basically a pulse generator and a synchroscope, combined into a single unit. It is used to generate, display, and measure pulse test signals. It consists of Pulse Generator SG-30/UP, its transit case, and the associated cables, adapters, accessories, and technical manuals. Operation of the equipment involves the use of high potentials which are dangerous to life. Safety precautions must be observed.

The Pulse Generator SG-30/UP has been designed to furnish rectangular voltages of adjustable duration, amplitude, and repetition frequency. These pulses are delayed so that they follow trigger pulses by an adjustable time interval. The equipment may be triggered by an external signal, or it may be triggered by an internally generated audio-frequency signal. Internally generated pulse, trigger, and audio signals are made available at output terminals on the front panel.

The synchroscope located in the same unit is capable of accurately determining the waveshape, amplitude, duration, and time relationship of the output pulses. The equipment is suitable for use in maintaining airborne or ground electronic equipment. The design and construction of the unit makes it adaptable for work performed in laboratories or in maintenance shops located aboard ship or on land.

MULTIPLE-SIGNAL GENERATORS

Signal Generator SG-321A/U provides multiple output signals which are essentially transient-free over a frequency range of 0.008

to 1200 cps in 5 bands. The versatility of the equipment and the quality of its generated signals make the SG-321 useful for any general purpose testing application within its frequency range. It is especially useful in the testing of servosystems and mechanically operating systems, and in the electrical simulation of mechanical operations.

The outputs available from this equipment include square and triangular waveforms, both of which are inherent in the basic oscillating system. In addition, a sine wave is developed by modifying (synthesizing) the triangular waveform. A sync output pulse is also made available for external use.

The basic oscillating systems uses a type of relaxation oscillator that is especially well adapted to the generation of very low frequencies. Both the triangular and the square wave of voltage as a function of time are inherent in the systems.

Any type of AVC system causes a delay in the stabilization of an output response following a change in operating frequency. The oscillating system of the SG-321A/U is a constant amplitude device which requires no AVC system. The output amplitude and distortion of signals is therefore almost completely independent of frequency.

The signal generator is rated to deliver at least 30 volts peak to peak to a 4000-ohm load. The sync output is a negative pulse of 10 volts amplitude and a duration of less than 5 microseconds. The sync pulse occurs at the crest of the sine wave, and at corresponding points on the other waveshapes.

SIGNAL ANALYZERS

Signal analyzers, while used in many different situations, generally aid in the accomplishment of only one function, that is to check the response of an equipment under simulated conditions of specific operations.

MODULATION MEASUREMENT

Modulation characteristics can be determined by waveform measurement or by use of modulation meters (which are special applications of basic test equipment). Modulation measurements are sometimes required during tuning procedures to adjust transmitting equipment for the proper amount of modulation. During maintenance tests of modulated transmitter equipment, the amount of distortion of the output signal and the modulation level or index should be determined.

The modulation level of carrier signals in multiplexing equipment is usually set at the factory or in the shop during corrective maintenance procedures. Proper adjustment of the input signal level and automatic signal level regulation circuits provide the correct amount of modulation. Defects in modulation circuits can be detected by measurements of the quality of the received signals. Corrective maintenance analysis of multiplex equipment modulation circuits can usually be made by signal level measurements. Therefore, specific modulation measurements are normally not required for a carrier equipment which operates in the audiofrequency to medium frequency RF range.

Most amplitude modulated radio transmitters which operate in the low frequency to high frequency range must be adjusted for correct modulation during normal tuning procedures. If the modulation level is low, the transmitter is not operating at its maximum efficiency; on the other hand, modulation in excess of 100 percent procedures serious distortion. Since either of these conditions is undesirable, amplitude modulation should be maintained between 60 and 95 percent when possible. The modulator amplifier gain can be initially adjusted by use of an oscilloscope or a modulation meter.

The modulation level or index of AM and FM radio transmitters which operate in the VHF range is usually adjusted by the manufacturer or in the shop during corrective maintenance. Amplitude modulation of radio transmitters in this frequency range can usually be measured by the same methods employed for transmitters in the LF to HF range.

Frequency modulation measurements can be obtained by the use of an audiofrequency signal generator and a receiver with a beat-frequency oscillator. The modulation index can also be determined by a comparison method, using a frequency-modulated signal generator having a calibrated modulation control, an AF signal generator, a radio receiver capable of detecting FM signals, and an output signal level indicator.

Pulse modulation of radar and radio signals can be measured by waveform displays presented by basic oscilloscopes or synchroscopes. The amount of usable energy in a pulsed waveform, as measured by a spectrum analyzer, is also an indication of the quality of pulse modulation.

WAVEFORM MEASUREMENT

Waveform measurements can be made by observing displays of voltage and current variations with respect to time, or by harmonic analysis of complex signals. Waveform displays are particularly valuable for adjusting and testing pulse generator, pulse former, and pulse amplifier circuits. The waveform visual display is also useful for determining signal distortion, phase shift, modulation factor, frequency, and peak-to-peak voltage.

The cathode-ray oscilloscope is commonly used for the analysis of waveforms generated by electronic equipment. Several types of cathode-ray oscilloscopes are available for making waveform measurements. The oscilloscope required for a particular test is determined by characteristics such as the input frequency response, the input impedance, the sensitivity, the sweep rate, and the methods of sweep control. The synchroscope is an adaptation of the cathode-ray oscilloscope which features a wideband amplifier, triggered sweep, and retrace blanking circuits which are desirable for the analysis of pulse waveforms.

Oscilloscopes are also incorporated in some harmonic analysis test equipment to display harmonic energy levels on a cathode-ray tube. To effectively analyze waveform displays, the correct waveshape must be known beforehand. This information can be obtained from technical manuals for the equipment or from previous measurements of the same circuits when they are operating correctly.

Harmonic analysis test sets can be used to determine the energy distribution in electrical signals. Frequency-selective circuits separate the signals into narrow frequency bands, and the energy in each band is indicated by a meter or displayed on a cathode-ray tube. A group of frequency-selective circuits can be connected in parallel, a single frequency-selective circuit can be tuned manually or automatically, or a heterodyne method (using a sweep generator and fixed-tuned circuit) can be used to select electrical power present in a narrow frequency band.

The panoramic adapter is a common harmonic analyzer used in conjunction with a radio receiver to present the energy distribution of radio signals. This equipment provides a visual indication of the power present in the carrier and sideband of radio signals. Spectrum analyzers are used for the tuning and maintenance of radar transmitters to determine whether the transmitted power is concentrated in a usable frequency band. The spectrum analyzer and the panoramic adapter normally use the heterodyne method to select frequency bands and a cathode-ray tube to display the signal strength with respect to frequency.

OSCILLOSCOPE

An oscilloscope is an electronic test set that displays information on the face of its cathode-ray tube (CRT). It is sometimes referred to as an "O" scope. The uses of an oscilloscope are many and varied, but it is used primarily to troubleshoot and aline electronic equipment; which is accomplished by observing and analyzing waveforms as to shape, amplitude, and duration. The service instruction manual for the particular equipment on which work is being performed will designate what waveforms are to be observed at the various test points throughout the equipment. Waveforms that will be observed at any one selected test point will differ, depending on whether the operation of the equipment is normal or abnormal.

The display observed on a cathode-ray oscilloscope is ordinarily one such as shown in figure 8-36. This illustration shows the instantaneous voltage of the wave plotted against time. Elapsed time is indicated by horizontal distance, from left to right, across the etched grid (graph) placed over the face of the tube. The amplitude of the wave is measured vertically on the graph.

The oscilloscope is also used to picture changes in quantities other than simply the voltages in electric circuits. If an electric current waveform is of interest, it is usually satisfactory to send the current through a

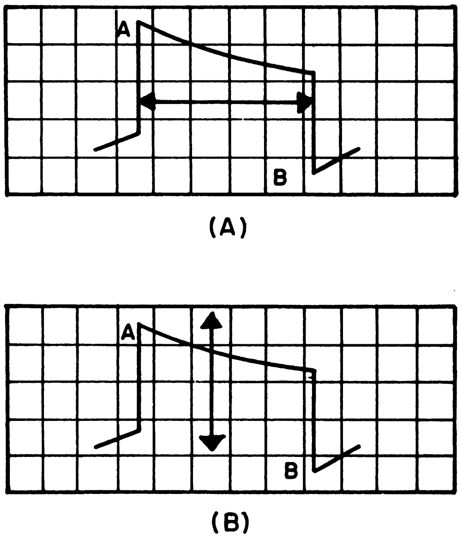


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Figure 8-36.—Typical waveform display.
(A) Measurement of elapsed time;
(B) measurement of voltage difference.

small series resistor and look at the voltage wave across the resistor with the oscilloscope. Other quantities such as temperatures, pressures, speeds, and accelerations can be translated into voltages by means of suitable transducers, and then viewed on the oscilloscope.

Interpreting the Display

To find the elapsed time between two points on the graph (fig. 8-36 (A)) such as A and B, multiply the horizontal distance between these points in major graduated divisions by the setting of the TIME/DIV (time per division) control. This control sets the horizontal sweep rate of the oscilloscope. The distance between points A and B is 4.8 major divisions. If the TIME/DIV control is set at 100 microseconds per division, then the elapsed time between points A and B must be 4.8 x 100 = 480 microseconds. In general, elapsed time = horizontal distance in divisions X TIME/DIV setting.

If a MULTIPLIER control is associated with the TIME/DIV control, multiply the above result by the setting of the MULTIPLIER. If a MAGNIFIER is in operation, divide the result by the amount of magnification.

To find the voltage (fig. 8-36 (B)) difference between any two points on the graph, such as A and B, multiply the vertical distance between these points in major graduated divisions by the setting of the VOLTS/DIV control. This control sets the vertical deflection factor or sensitivity of the oscilloscope. The vertical distance between points A and B is 4.0 divisions: If the VOLTS/DIV control is set at 0.5 volts per division, then the voltage difference between points A and B must be 4.0 x 0.5 = 2.0 volts.

The quantity called pulse repetition rate (or pulse repetition frequency) for periodic pulses can be expressed as the number of pulses per unit of time. Examples: 10 pulses per second and 50 pulses per microsecond.

In using the oscilloscope to measure the frequency or repetition rate of periodic waveforms, first read the horizontal distance in major divisions between corresponding points on two succeeding waves. This is the horizontal distance occupied by one cycle of the wave. Multiply this by the setting of the TIME/DIV control in seconds, milliseconds, or microseconds. Take the reciprocal of this product; that is, divide it into 1. The result is the desired frequency or repetition rate.

It is convenient to use square waves, rather than other forms of waves, for testing of equipment because the nature of a defect, rather than simply its presence, is suggested by the kind of distortion which occurs to a square wave. By observing the squarewave response, it is easy to tell whether the transmission of low or high frequencies is affected. This observation is not so well separated with regard to frequency if waves other than square waves are used.

If two linear devices give identical responses when square waves are fed into them, they can, in general, be expected to give responses similar to each other when other waveforms are fed into them.

Information Contained in a Square Wave

It can be shown that a periodic wave contains the following components; (1) a fundamental wave, which is a sine wave having a frequency equal to the repetition frequency of the square wave, and (2) an infinite series of harmonics—sine waves having frequencies which are equal to whole numbers multiplied by the fundamental frequency. The harmonics must be properly related in phase and in amplitude to the fundamental.

Waveform D of figure 8-37 depicts a periodic rectangular wave (square wave). In the case of the square wave, the only harmonics present are the "odd" harmonics (those whose frequencies are equal to the fundamental frequency multiplied by odd whole numbers); and the strengths of the harmonics vary in inverse proportion to the frequencies of the harmonics, the fifth harmonic being one-fifth as strong as the fundamental, for example. The way in which these waves combine to make up a square wave is suggested by figure 8-37.

The four curves shown in figure 8-37 illustrate the following:

1. Curve A the fundamental sine wave.
2. Curve B the sum of the fundamental and third harmonic.
3. Curve C the sum of the fundamental plus third and fifth harmonics.
4. Waveform D is the ultimate square wave.

It will be noted that the first few harmonics combine with the fundamental to provide an approach to an actual square wave. Additional harmonics, of higher frequencies, would cause the leading edge of the wave to rise more rapidly, and produce a sharper corner between the leading edge and the top of the wave. It would require an "infinite" range of harmonics to produce a truly vertical leading edge and an actual sharp corner, and this situation is physically impossible to produce. But waves can be generated which are very close to this ideal situation. (The same considerations apply to the falling edge of the waveform, and the following corner.)

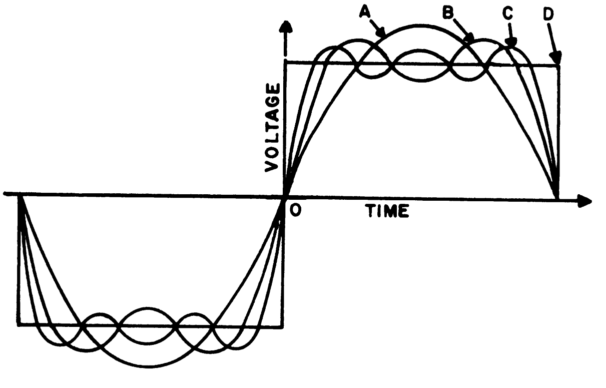

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Figure 8-37.—Addition of harmonics to fundamental waveform.

Information regarding the amplitude and phase relationships of the higher harmonics is, then, contained in the leading-edge steepness and in the sharpness of the corner.

If low frequency components (fundamental and the first few harmonics) are not present in the proper amounts and in the correct phase relationships, the part of the square wave affected will be the flat top. Figure 8-38 (A) shows the location of the low and high frequency information in a square wave. Low frequency defects will appear in the form of slope or general curvature in the top, as shown in (B) and (C) of the figure. In (B) of the figure, the low frequency components have leading phase angles and are attenuated. In (C) the low frequency components have lagging phase angles and are accentuated.

Oscilloscope Block Diagram

Figure 8-39 is a block diagram of a typical oscilloscope, omitting power supplies. The

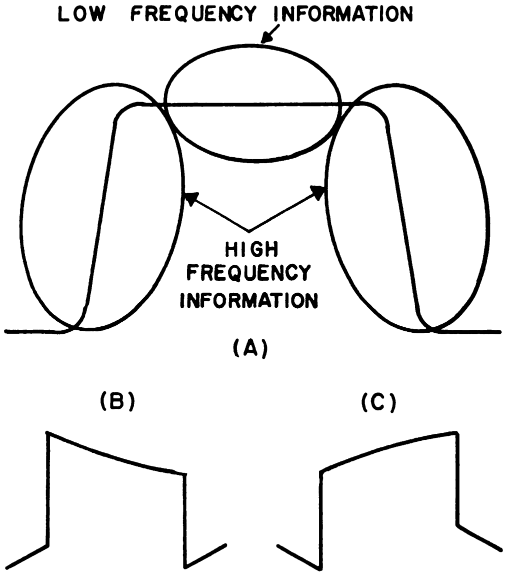

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Figure 8-38.—Information found in a square wave.

waveform (A) to be observed is fed into the vertical amplifier input. The calibrated VOLTS/DIV control sets the gain of this amplifier. The push-pull output (B and C) of the vertical amplifier is fed through a delay line to the vertical deflection plates of the cathode-ray tube.

The time base generator or "sweep generator" develops a sawtooth wave (E) that is used as a horizontal deflection voltage. The rising or positive-going part of this sawtooth, called the "runup" portion of the wave, is linear. That is, it rises through a given number of volts during each unit of time. This rate of rise is set by the calibrated TIME/DIV control. The sawtooth voltage is fed to the time base amplifier. This amplifier supplies two output sawtooth waveforms (G and J) simultaneously—

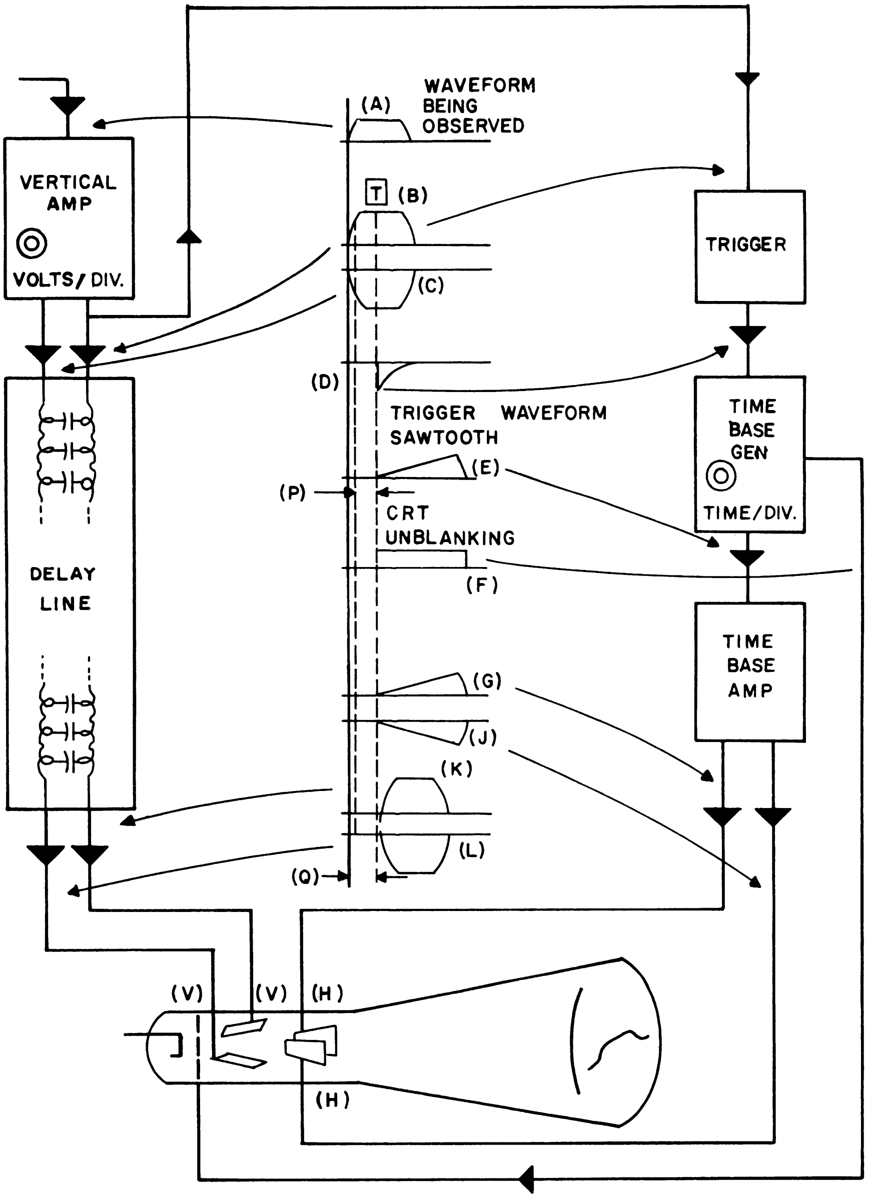

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Figure 8-39.—Typical oscilloscope block diagram.

one of them positive-going, like the input, and the other negative-going. The positive-going sawtooth is applied to the right-hand horizontal deflection plate of the cathode-ray tube, and the negative-going sawtooth is applied to the left-hand deflection plate. As a result, the cathode-ray beam is swept horizontally to the right through a given number of graduated divisions during each unit of time, the sweep rate being controlled by the TIME/DIV CONTROL.

In order to maintain a stable display on the cathode-ray tube screen, each horizontal sweep must start at the same point on the waveform being displayed. To accomplish this, a sample of the displayed waveform is fed to a "trigger" circuit which gives a negative output voltage spike (D) at some selected point on the displayed waveform. This triggering spike is used to start the rising portion of the time base sawtooth. As far as the display is concerned, then, "triggering" can be taken as synonymous with the starting of the horizontal sweep of the trace at the left-hand side of the grid.

The rectangular "unblanking" wave (F) derived from the time base generator is applied to the grid of the cathode-ray tube. The duration of the positive part of this rectangular wave corresponds with the duration of the positive-going or rising part of the time base output, so that the beam is switched on during its left-to-right travel and is switched off during its right-to-left retrace.

In many cases the leading edge of the waveform being displayed is used to actuate the trigger circuit. Yet it may be desirable to observe this leading edge on the screen- and the triggering and unblanking operations require a measurable time (P), often about 0.15 microsecond. To permit the leading edge to be seen, a delay (Q) of about 0.25 microsecond is introduced by the delay line in the vertical deflection channel after the point where the sample of the vertical signal is tapped off and fed to the trigger circuit.

The purpose of the delay line is to retard the application of the observed waveform to the vertical deflection plates until the trigger and time base circuits have had an opportunity to begin the unblanking and horizontal-sweep operations. This permits viewing the entire desired waveform—even though the leading edge of that waveform was used to trigger the horizontal sweep.

If the delay line were not used, only that portion of the waveform following the instant (T) in waveform (A) could be seen.

Oscilloscope Probe

The input circuit to the vertical amplifier of an oscilloscope can be simulated by a high resistance R shunted by a small shunt capacitance C, as shown in figure 8-40.

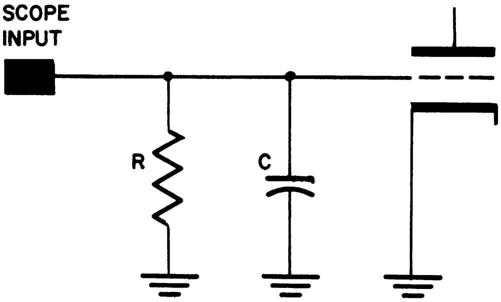

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Figure 8-40.—Oscilloscope vertical amplifier input circuit.

In some applications, even this high resistance and small capacitance can produce undesirable loading upon the circuit whose waveforms are being examined by means of the oscilloscope. This loading can cause the oscilloscope presentations to be different from the waveforms that would be present with the oscilloscope disconnected. One use of a passive probe is to reduce this resistive-capacitive loading on the circuit under investigation.

The probe includes a resistor R_p shunted by a capacitor C_p, (fig. 8-41). This combination is connected in series with the inner conductor of the cable to the oscilloscope input. The result is that, when the probe is connected to the circuit under investigation, there is connected to that circuit a new effective loading capacitance smaller than the original capacitance C and a new effective loading resistance larger than the original resistance R. Thus the loading effect of the

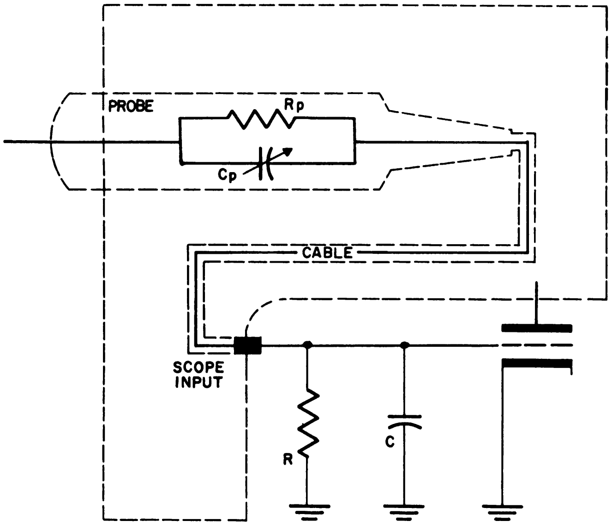

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Figure 8-41.–Oscilloscope vertical amplifier using a passive probe input.

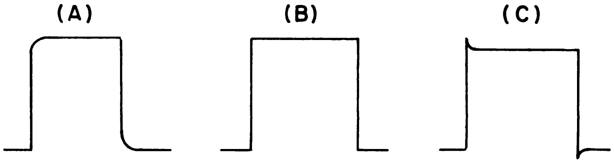

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Figure 8-42.–Effects of probe adjustment.

oscilloscope input-circuit on the circuit under investigation is reduced through the use of the probe.

A second effect of the probe is to reduce the amount of signal voltage applied directly to the oscilloscope input connection for a given amount of original signal voltage. This occurs because of the voltage-divider action of R_p and R. This effect is taken into account in the "attenuation ratio" marked on the probe. Thus if the probe is marked "10X ATTEN" all oscilloscope voltage indications must be multiplied by 10.

If an oscilloscope equipped with a probe is used to look at a square wave, and the probe capacitor C_p is too small, some of the high frequency components of the square wave will be bypassed around the oscilloscope input terminals by the input capacitance C. Thus the steepness of the leading edge of the displayed square wave is reduced. (See fig. 8-42 (A)).

If the probe capacitor is adjusted to the correct value, a compensating amount of high frequency information is bypassed around the probe resistor R_p to make up for the loss through C, and the leading edge of the displayed square wave will be restored to its original steepness (B). If C_p is made too large, the high frequency response of the circuit will be overcompensated and apply too much high frequency information to the oscilloscope input connection. This results in an overshoot in the displayed waveform that was not present in the original (C). C_p can be adjusted to its correct value by using the probe to display the square wave generated by the voltage calibrator that is a part of the oscilloscope. Adjustment is made to display a square wave with as flat a top as possible.

Probe adjustment must be checked whenever a probe is used with an oscilloscope or a plug-in preamplifier that has an input capacitance different from that of the instrument with which the probe was previously used.

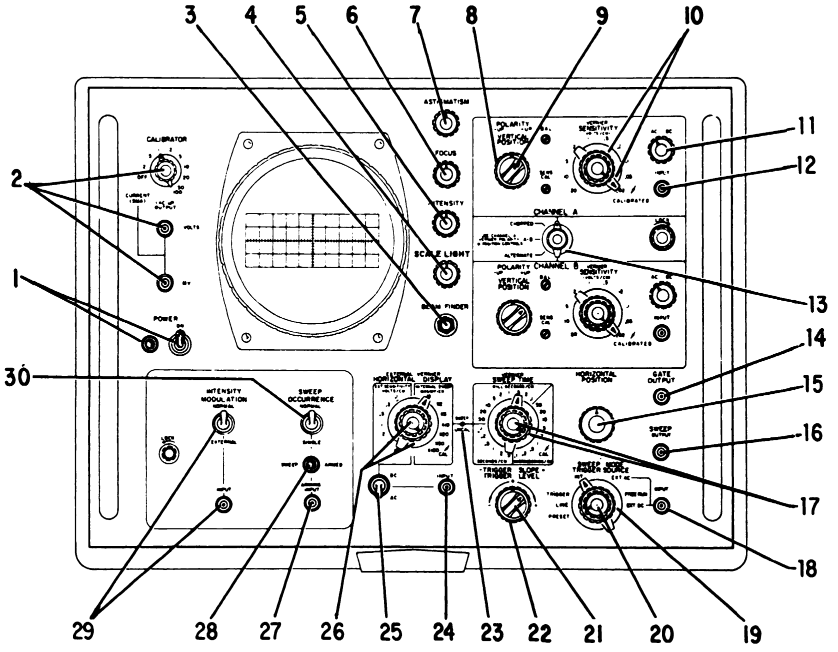
NOTE: As indicated in figure 8-42, the attenuation achieved is a result of R as well as R_p, which means that, though probes may be swapped for use with other types of oscilloscopes, the calibration may be in error, even though the waveform distortion may possibly be adjusted out.

AN/USM-140B Oscilloscope

The front panel arrangement of a dual-channel oscilloscope that was especially designed for general purpose use is shown in figure 8-43. Most of the controls and connectors normally used by the operator are indicated in the figure and are self-explanatory. Those that are not are listed and described below.

CALIBRATOR switch (item 2): This switch is used to control the output of the self-calibrator which supplies a 1-kHz signal used as a standard to check the accuracy of the vertical and horizontal sensitivity selectors. The signal is available at either of the two connectors just below the switch depending on the amplitude required. Amplitude of the signal is controllable from 0.2 millivolts to 100 volts.

ASTIGMATISM control (item 7): This control adjusts the sharpness of the trace. It is used in conjunction with the focus control.



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1. Power ON-OFF/indicator lamp.
2. Calibrator switch and connectors.
3. Beamfinder.
4. Scale illumination.
5. Intensity control.
6. Focus control.
7. Astigmatism control.
8. Vertical position.
9. Polarity switch.
10. Sensitivity switch.
11. Ac-dc switch V.
12. Channel A input.
13. Channel selector
14. Gate output.
15. Horizontal position.
16. Sweep output.
17. Sweep time.
18. External trigger.
19. Trigger source.
20. Sweep mode.
21. Trigger slope.
22. Trigger level.
23. Sweep uncal.
24. Horizontal input.
25. Ac-dc switch H.
26. Horizontal display.
27. Arming input.
28. Sweep armed.
29. Intensity modulation.
30. Sweep occurrence.

Figure 8-43.–Oscilloscope AN/USM-140B.

POLARITY switch (item 9): This switch selects the type of input coupling. Either capacitive for a-c signals or direct for d-c signals. Channel B has an identical control.

GATE OUTPUT (item 14): The gate output provides a +50-volt unblanking pulse during horizontal sweep time.

SWEEP OUTPUT (item 16): The sweep output provides a voltage ramp of approximately -50 to +50 volts coincident with the horizontal sweep.

TRIGGER SOURCE (item 19): The trigger source selects the source of the signal to be used to trigger the sweep.

SWEEP MODE (item 20): The sweep mode provides a variable sensitivity adjustment for the sweep circuit. It also allows for the selection of either a triggered or a free running sweep.

TRIGGER SLOPE (item 21): This switch selects the portion of the waveform used to trigger the sweep either positive or negative.

This instrument is a high-speed, precision oscilloscope for displaying the waveforms of electrical voltages that range from a frequency of 22 megahertz to direct current. Vertical deflection sensitivity ranges from 20 millivolts to 200 volts per centimeter. Horizontal deflection sensitivity ranges from 0.1 volt to 100 volts per centimeter at frequencies from direct current to 1 megahertz per second.

The sweep generator, which is a part of the horizontal deflection system, provides a variable range of sweep times to allow the operator to display one or several cycles of the waveform, as required. The sweep rates are adjustable from 0.1 microsecond to 5 seconds per centimeter. A vernier control in the sweep circuit can be used to extend the slowest sweep to 15 seconds per centimeter. The sweep can be synchronized by an external signal or by the signal being viewed. Polarity and sensitivity of synchronization are selectable to permit synchronization from different points on complex waveforms. Sweep rate, expansion, and sensitivity are direct reading controls and are provided with potentiometer type continuous adjustment between each of the calibrated step selections.

Two identical probes with a 10 to 1 attenuation are provided in addition to an assortment of connector adapters and two coaxial cables to facilitate connecting the oscilloscope to the variety of equipment with which it can be used.

Maintenance of the oscilloscope by operating personnel is limited to checking and adjusting vertical sensitivity and balance, cleaning the air filter in the cooling air inlet, and replacing fuses. In many cases a calibration adjustment is required when replacing tubes and semiconductors. Therefore, only qualified technicians should attempt replacement of such parts. Operating personnel other than those qualified to make calibration adjustments should refrain from repair of this type except in an emergency.

The useful life of an oscilloscope can be materially extended by using normal care in handling and operating. When in use, the area behind the cooling air inlet must be kept clear to allow flow of the cooling air through the ventilating door. This oscilloscope is provided with a thermal switch to protect it from overhearing. If the instrument goes off during use, removal of the dual trace preamplifier plug-in unit will allow the operator to view a neon type indicator lamp. If the lamp is lit, the oscilloscope is overheated. Turn off the power and investigate the cause of overheating.

CAUTION: This instrument contains voltages as high as 8,600 volts, which can be fatal. Turn the instrument off before touching any internal part.

SYNCHROSCOPE

The synchroscope, which is widely used in radar testing, is an adaptation of the oscilloscope. A trace is produced only when it is initiated by an input trigger, as contrasted with the continuous sawtooth sweep provided by the oscilloscope. Synchroscope circuits are similar to oscilloscope circuits except for the signal channel and the sweep channel. These circuits are shown in block diagram form in figure 8-44.

The signal channel of a typical synchroscope includes an input circuit, which is usually in the form of a 72-ohm adjustable-step attenuator. Various degrees of attenuation are available, and the dial is calibrated to indicate how much attenuation is present. The attenuator insures that all signals, regardless of amplitude, produce approximately the same input level to the amplifier section.

Following the attenuator is an artificial delay line, which is a low pass filter with a cutoff frequency higher than the highest frequency to be passed, and which has an impedance of 72 ohms. The delay line is terminated with a 72-ohm gain control. One purpose of the delay line is to delay presentation of the signal to be observed until the sweep trace has been initiated by an undelayed portion of the input signal. If the delay line were not used, the initial portion of the waveform would not appear on the trace, because a certain amount of time is required for the input signal voltage to rise to the level needed to trigger the sweep circuit. With the delay line in use, the signal does not reach the amplifier until one-half microsecond after the trace starts; as a result, the entire pulse is seen. A secondary purpose of the delay line is to provide, by means of reflection, a series of accurately spaced pulses suitable for calibration of short time intervals.

To accomplish the secondary purpose, a switch is provided to cause a mismatch in the termination of the delay line. When a sharp pulse is applied into the line, a series of reflections occurs similar to those shown in figure 8-45. Since the time required for a pulse to travel down the line and back is 1 microsecond, a series of pulses occurring 1 microsecond apart is produced. Each successive pulse is smaller because of the losses in the delay line, but enough pulses

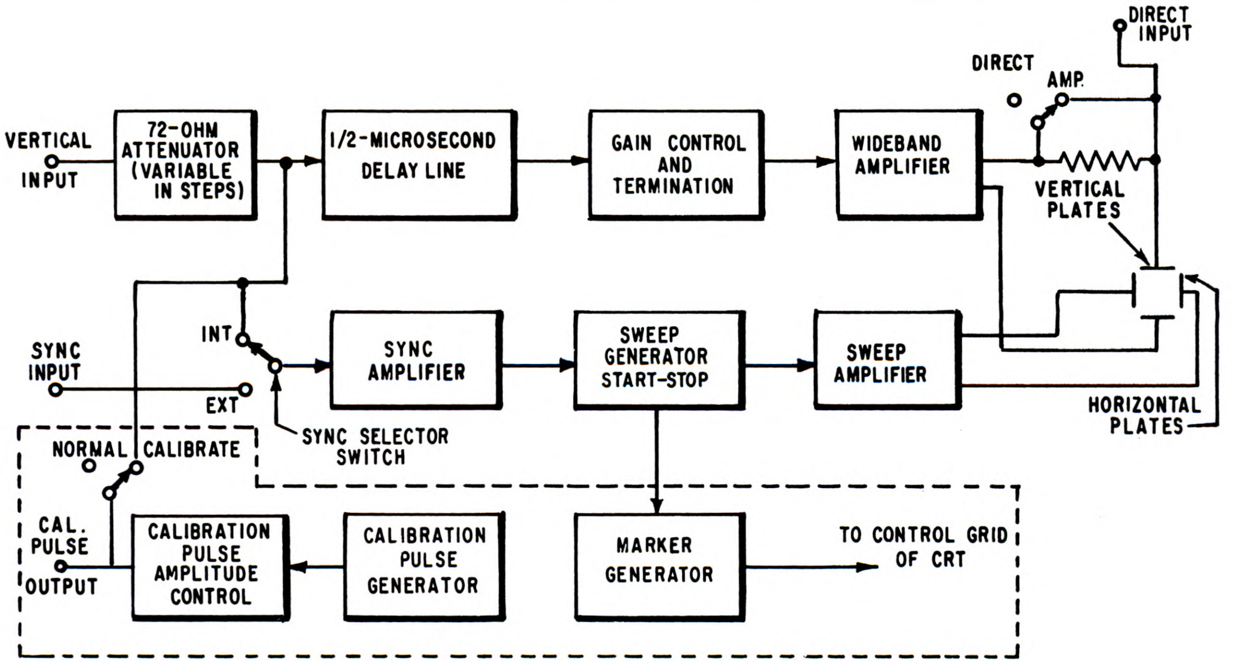

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Figure 8-44.—Typical synchroscope, block diagram.

are visible for most high speed calibration purposes.

The gain control feeds a wideband or video amplifier, which is connected to the vertical deflection plates. In addition, an external connection is provided to the vertical plates.

The horizontal circuit consists of a sync switch for either internal or external sync, a sync amplifier with a gain control, and a start-stop sweep generator, which will not develop a sweep voltage until a pulse of sufficient amplitude is supplied. The duration of the sweep, or sweep speed, is made adjustable from a very few microseconds to about 250 microseconds. The sweep generator is followed by a conventional horizontal amplifier. Since the trace is triggered by the input signal, the synchroscope may be used to observe nonperiodic pulses, such as those occurring in a radar system with an unstable PRF generator.

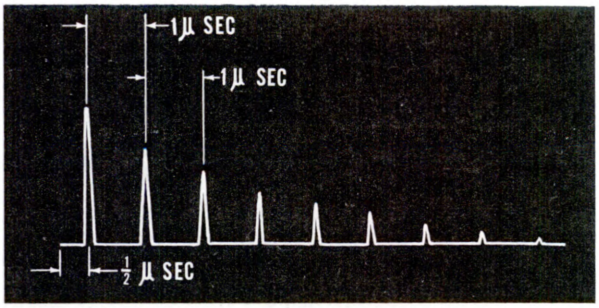

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Figure 8-45.—Pulse reflection on a mismatched line.

In later designs, it is common to find provisions for calibration of input voltages and sweep time. Voltage calibration is made by comparing the unknown voltage with a variable-voltage pulse of known value, generated internally. The calibrating pulse is adjusted to be equal in amplitude to the unknown voltage; the value is then read from the dial that controls the calibrating pulse. Sweep time calibration is made with the aid of marker pulses produced by accurately adjusted tuned circuits. The marker pulses appear on the trace as a series of bright dots spaced at intervals chosen by the operator. In a typical synchroscope, marker intervals of 0.2, 1, 10, 100, and 500 microseconds may be selected in accordance with the time duration of the pulse under test; for greater accuracy, interpolation may be used.

SPECTRUM ANALYZER

During the modulation of a radiofrequency carrier wave by keying, by speech or music, or by pulses, the resulting wave contains many frequencies. The original carrier is present, together with two groups of new frequencies called the sideband components. One group of sidebands is displaced in frequency below the carrier. The other group is displaced above the carrier. The distribution of these frequencies when shown on a graph of voltage or power against frequency is called the spectrum of the wave.

A spectrum analyzer is a device for exhibiting the spectrum of modulated waves in the radiofrequency range and in the microwave region.

In principle, the spectrum analyzer operates by tuning through the frequency region in question, using a narrowband receiver. The output of the receiver is measured, usually by means of a cathode-ray oscilloscope, and the plot on the screen is a graph of voltage versus frequency.

The device is essentially a superheterodyne receiver with a very narrowband intermediate frequency amplifier section. The local oscillator frequency is varied between two values at a linear rate. The frequency-control generator which governs the frequency of the local oscillator also produces the horizontal sweep voltage for the cathode-ray tube deflection plates. (See fig. 8-46.) As a result, each position of the beam corresponds to a definite frequency value; and the display is a graph in which the X-axis is interpreted in terms of frequency.

The output of the detector in the receiver is amplified and applied to the vertical deflection plates so that the beam is deflected vertically by an amount proportional to the voltage developed in the detector (and amplifier).

The signal to be analyzed is fed into the mixer stage of the receiver. The local oscillator changes in frequency at a linear rate, beating with each of the signal frequency components in succession to form the intermediate frequency of the narrowband amplifier. The output of the IF amplifier is detected, amplified, and applied to the vertical deflecting plates.

Spectrum analyzers designed for analysis of microwave signals are equipped with klystron tubes in the local oscillator stage. In analyzers

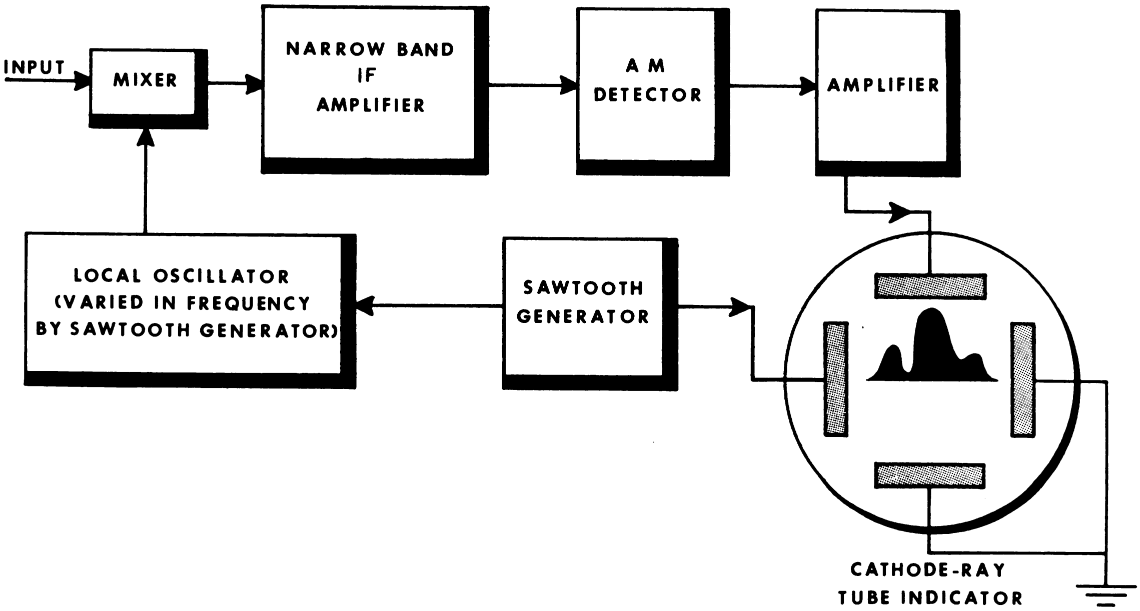
INPUT
MIXER
NARROW BAND IF AMPLIFIER
A M DETECTOR
AMPLIFIER
LOCAL OSCILLATOR (VARIED IN FREQUENCY BY SAWTOOTH GENERATOR)
SAWTOOTH GENERATOR
CATHODE-RAY TUBE INDICATOR

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Figure 8-46.—Typical spectrum analyzer, block diagram.

adapted for lower frequency RF signals, triode oscillators are used which are varied by means of reactance-tube modulators.

Spectrum analyzers are employed extensively in studying the output of pulse radar transmitter tubes such as the magnetron. In this kind of analysis, unwanted effects such as frequency modulation of the carrier can be easily detected. In pure amplitude modulation of a carrier wave by a square pulse, the spectrum is symmetrical about the carrier frequency. Lack of symmetry indicates the presence of frequency modulation. A spectrum representing the ideal condition is shown in (A) of figure 8-47.

Examples of undesirable magnetron spectra are shown in (B) and (C) of figure 8-47. These forms indicate trouble in the modulator, the tuning system, or in the magnetron tube itself.

The carrier frequency is best defined as the center frequency in a symmetrical spectrum such as that shown in (A) of figure 8-47. In some analyzers this principle is used as a means of carrier frequency measurement. A sharply resonant circuit is provided in the receiver which acts as a trap to prevent an extremely narrow range of frequencies from appearing in the output of the IF amplifier. The result of its use is that a gap appears in the display, and the gap corresponds to the resonant frequency of the trap. The adjustment of the trap is calibrated in frequency, and the circuit can be adjusted to make the gap occur in the center of the spectrum. The frequency of the carrier is then read from the calibration of the trap.

For an additional coverage of spectrum analyzers, consult Basic Electronics, NavPers 10087-B. Also, a discussion of spectrum analyzers appeared in the June 1963 issue of the DIGEST. That article is recommended for personnel desiring additional information concerning this class of test equipment.

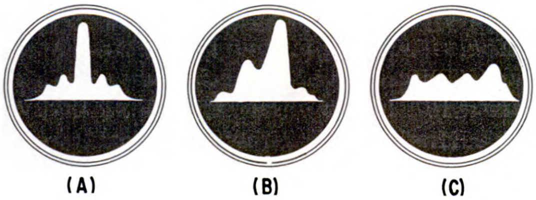


Figure 8-47.—Frequency spectra.

WAVE ANALYZER

The wave analyzer is used to measure amplitude and frequency of the components of a steady state complex electrical waveform. These include the components of harmonic distortion, intermodulation distortion, hum, and noise.

Specific uses of the wave analyzer include the measurements of distortion components in AF equipments; radio receivers and transmitters; oscillators, amplifiers, and vacuum tube circuits in general; harmonic studies of electrical power system and electrical machinery, hum measurement in a-c operated communication equipment; and noise analysis. As a sharply tuned voltmeter, it is useful in the measurement of the transmission characteristics of electric wave filters and as a null detector for impedance bridges. The unit may be used as a detector for intermodulation distortion measurements when a two-signal audio generator is used as a source.

The wave analyzer discussed in the following paragraphs is a heterodyne type vacuum tube voltmeter. The IF amplifier includes a selective filter using three quartz crystals. The use of a heterodyne method makes it possible to vary the frequency response while using a fixed frequency filter.

The output of the local oscillator and the whole of the complex waveform to be examined are fed to a balanced modulator where their combination produces both sum and difference frequencies, or sidebands in the output. The original of the complex waveform is not passed by the modulator intermediate frequency output transformer and the local oscillator carrier frequency is suppressed in the output because of the two-tube, balanced modulator employed.

The 50-kHz component of the upper sideband, proportional to the voltage of that frequency present in the original wave to which the main dial is set, is selected and amplified by the intermediate stages. The step attenuators provide for measurement of a wide range of voltages.

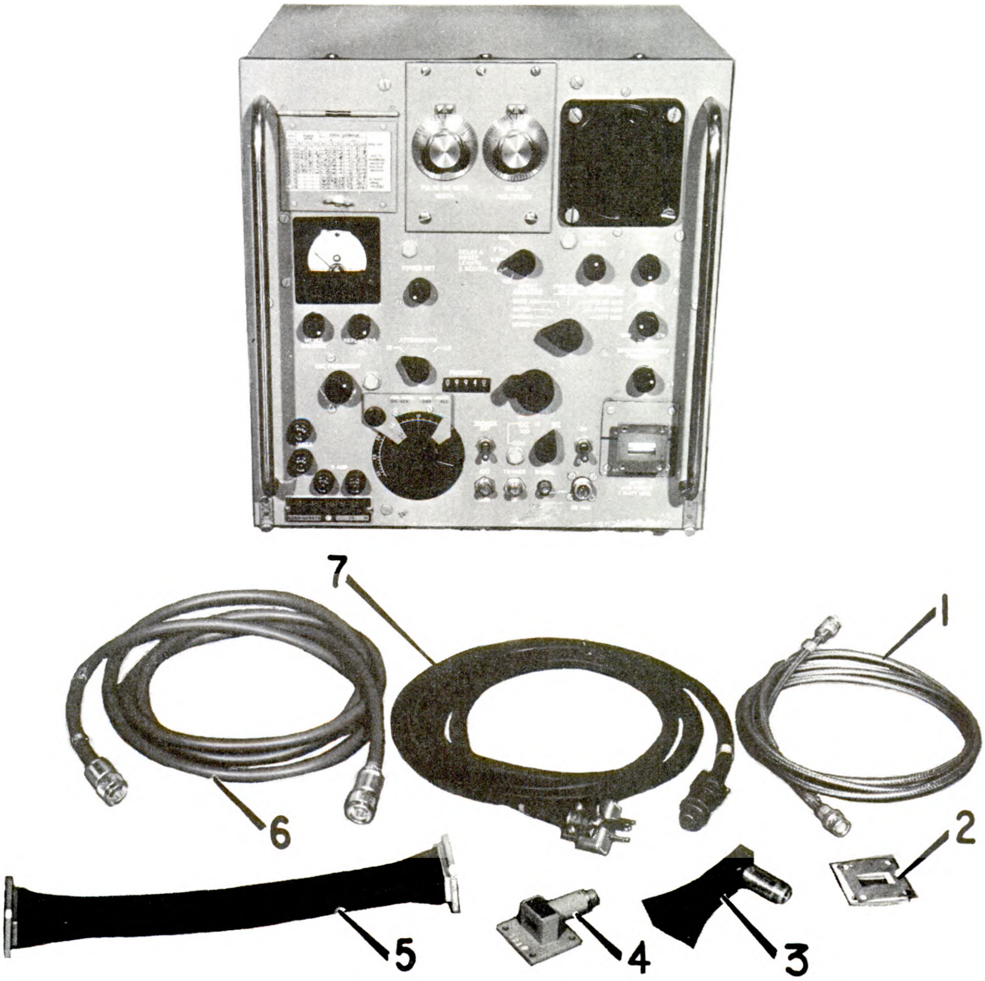
The equipment is mounted in a shielded oak cabinet, and all critical parts are hermetically sealed.

A detailed discussion of wave analyzers is beyond the scope of this training manual, but the foregoing discussion should serve to familiarize the technician with some of the basic principles used in the design of a wave analyzer.

MULTIPLE-FUNCTION EQUIPMENT FOR SYSTEMS TESTING

The numerous and complex operations required for servicing and maintaining radar requires, in some instances, numerous classes of test equipment. Therefore, a test set such as the UPM-32, combining the functions of several test sets, is very practical. This combination test set performs most of the functions necessary for radar maintenance in its frequency range.

This test equipment (fig. 8-48) is portable and is designed primarily for use with radar systems operating in the frequency range of 8,500 to 10,500 MHz. It functions as a power meter, a frequency meter, a spectrum analyzer, a signal generator, and a general purpose syn-



1. Cable assembly.
2. Gaskets.
3. Test antenna.
4. Adapters.
5. Waveguide.
6. RF cable.
7. Power cable.

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Figure 8-48.–Radar Test Set UPM-32.

chroscope. The general capabilities of the test set are as follows:

1. Measurement of power, frequency, spectrum, and frequency pulling of conventional and multipulsed radar transmitters.
2. Measurement of sensitivity and bandwidth of a radar receiver.
3. Measurement of the frequency and spectrum of a radar receiver's local oscillator.
4. Adjustment of a radar receiver's local oscillator.
5. Measurement of TR recovery time.
6. Observation of video signals.
7. Providing pulsed, FM, or CW microwave signals.

Radar Test Sets AN/UPM-32 (for X-band radars) and AN/UPM-44C (for S-band radars) are very similar in function and in operation. Each is usable for the same general functions. Both are generally reliable instruments, but are susceptible to mixer crystal damage due to improper manipulation of the control. For this reason, every technician should receive a thorough indoctrination in the proper use and operation of these equipments when they are available in his particular shop. Although this requirement is generally applicable for all test equipment (and other electronic equipments), it is especially important in equipments where the probability of damage from improper operating procedures is so great.

LINE TEST EQUIPMENT

The purpose of this section is to discuss some of the more common test sets that are used during line maintenance by Organizational Maintenance Activities. It is not intended that this discussion be all inclusive of all line test equipment, but only some of the more common line test sets.

The majority of line test equipment are of the GO - NO GO type. In other words, the test set indicates that the electronic system under test does or does not meet the minimum acceptable standard. Some of the more intricate line test equipment can be used to determine faulty units (black boxes) of a system. Operational tests of a system after installation of a repaired unit may also be made with this type of test equipment.

IFF

Radar Test Set AN/UPM-8B is a portable, a-c operated instrument, designed to perform rapid preflight checks of installed transponders, such as those of the Mark X IFF system. Its testing capabilities include checking the above transponders when they are operated in association with Selective Identification Feature (SIF) coding equipment, such as Coder Group AN/APA-89. The following features of transponders or associated SIF equipment can be checked simultaneously:

1. Transmitted frequency.
2. Relative transmitter power output.
3. Decoding of mode 1, 2, or 3 interrogations (challenges).
4. Reply coding (number but not spacing of pulses for Mark X).
5. Receiver frequency.
6. Relative receiver triggering level.
7. Proper code configurations (when SIF equipment is employed).
8. Pulse spacing (when SIF equipment is employed).

The results of these checks are simultaneously resolved into a single REJECT or ACCEPT indication of an operating panel meter. The REJECT-ACCEPT meter on the operating panel may also be used to give an indication of the general operating condition of the test set itself.

TACAN

Radio Test Set AN/URM-101A is a lightweight, easy-to-use unit developed to provide preflight check of the normal operation of airborne TACAN sets. The test set may be hand-carried to the vicinity of the aircraft equipped with the radio set and placed on the deck, or any other suitable support. During operation of the test set, visual and aural indications at the radio set will enable an observer to determine, whether the radio set is operating properly. The test set receives from and transmits to the TACAN radio set either by radiation from the antenna or by a direct connection with a coaxial cable. The test set will operate with up to four TACAN radio sets simultaneously.

The test set simulates signals such as those produced by Radio Beacon Set AN/URN-3, and which would normally be received by airborne TACAN sets at a particular bearing and distance from the beacon set. The test set generates a continuous tone signal, which provides aural indication when received. The test set transmits a continuous pulse train consisting of main and auxiliary reference pulse groups (bursts), identity pulses and equalizing pulses. In addition, when interrogated, it introduces reply pulses delayed to simulate distances of 5 miles and 100 miles. All of these pulses are amplitude-modulated with 15 and 135 hertz sine waves and are synchronized to give a bearing display of 140° on the airborne azimuth indicating equipment. A power output level control adjusts the RF unit to a constant power output, which is indicated on a panel meter. A range switch sets the desired 5-mile or 100-mile delay.

RADAR

The echo box is used in field testing, troubleshooting, and adjustment of pulsed type radar systems. Although simple in construction and operation, it is versatile in its applications. Properly used within its design limitations, the echo box can frequently eliminate the need for a complex test setup and an elaborate step-by-step testing procedure. The echo box uses passive circuitry, which does not require any external power (other than that of the radar set whose signal is to be analyzed). External power requirement is a critical factor with most other test sets.

The echo box is similar to a tuned cavity frequency meter, with additional capabilities. The tuned cavity frequency meter can be used to measure the frequency of CW or pulsed RF signals in the microwave range. The echo box, however, has no practical application in the testing or analysis of CW equipment signals. Figure 8-49 indicates the basic functional elements of a typical echo box.

Energy from the radar transmitter is fed through the directional couplers to the resonant cavity. When the cavity length is properly adjusted, resonant oscillations are set up by each

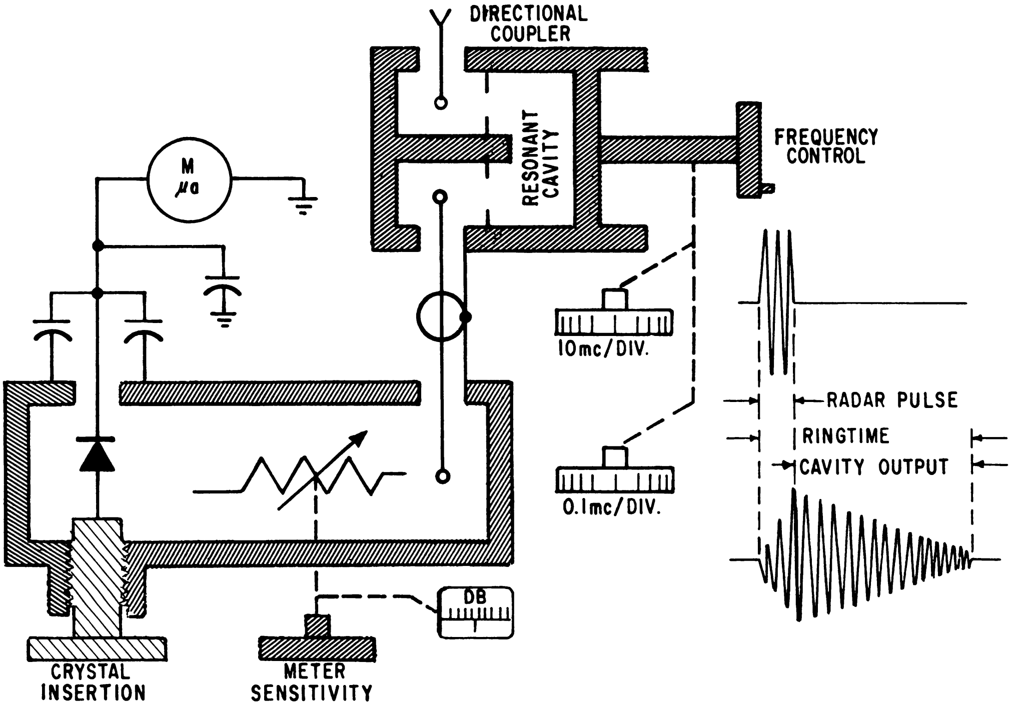

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Figure 8-49.–Typical echo box, functional circuit.

successive pulse of microwave energy. Maximum amplitude of oscillation occurs when the cavity is tuned precisely to the signal frequency. These cavity oscillations are detected by the crystal diode and indicated on the meter as an average d-c current. The amplitude of oscillation and the average current reading are proportional to the transmitter power output.

Oscillations in the tuned cavity are also coupled back to the radar set under test, where it is processed as an echo signal. This signal, when viewed on the indicator CRT, permits analysis of the radar pulse, and presents an indication of the general operating condition of the radar set.

Due to the manner in which the energy builds up in the cavity, saturation of the cavity is possible. If saturation does occur, distortion of the waveform and erroneous values of the measurements result. If the directional couplers do not prevent cavity saturation, additional attenuation must be provided.

A fairly complete functional analysis of the operating condition of a radar set can be obtained through analysis of the displayed waveform. Among the most important of the factors that can be determined are frequency and bandwidth, power and frequency spectra, sensitivity, pulse width and condition, and recovery time. Analysis of the waveform can also prove helpful in locating the cause of malfunctions within the radar set.

It must be remembered, however, that the echo box presents only relative (rather than absolute) values of power and sensitivity, and only rough values of frequency. Accuracy of these quantities is not comparable to the corresponding values obtainable from a spectrum analyzer. The primary value of the echo box lies in its regular usage. For maximum benefit, the values obtained from a given test must be compared to corresponding values obtained from a test on a radar set known to be operating properly.

In general, however, the echo box is an extremely valuable instrument. When used in a continuing maintenance program, it can enable the operator to maintain his equipment in peak operating condition. It can also provide him with indications of deterioration before actual malfunctions occur.

For personnel desiring additional information concerning echo boxes, the October 1965 issue of the DIGEST is recommended.

ALTIMETER

Delay Line MX-1381/APM-66 (fig. 8-50) is a portable unit of the Radar Test Set AN/APM-66 and consists of a coaxial cable delay line and two horn-type antennas. The two horns are connected together by a length of RG-55/U cable that is wound on two drums within the unit.

When the delay line unit antennas are mated with the altimeter receiver-transmitter antennas, the RF output of the transmitter is fed into one of the horn antennas, passes through the coaxial cable to the other antenna, and is fed out to the receiving antenna of the altimeter where it arrives delayed in time by an amount that is equal to the propagation time (electrical length) of the coaxial cable. This produces an altitude signal in the altimeter that is identical to that produced in normal altimeter operation when the altimeter is at an altitude that yields the same total propagation time down to the terrain and back again. Since two-way propagation is involved in normal operation, the altitude signal produced by a delay line will be equal to one-half the electrical length of the cable.

The length of the coaxial cable required for a delay line of this type may be determined from the formula:

$$L = V \times \text{altitude} \times 2$$

Where

L = physical length of the cable

V = velocity of wave propagation of the cable.

The delay line contains 228 feet of cable (330 electrical feet) and produces an altitude signal of 165 feet. The total attenuation of the cable and the two antenna horns is such that the altimeter that produces an altitude indication of 165 feet, minus the residual altitude, when coupled to the delay line can be considered as having adequate sensitivity for normal flight operation.

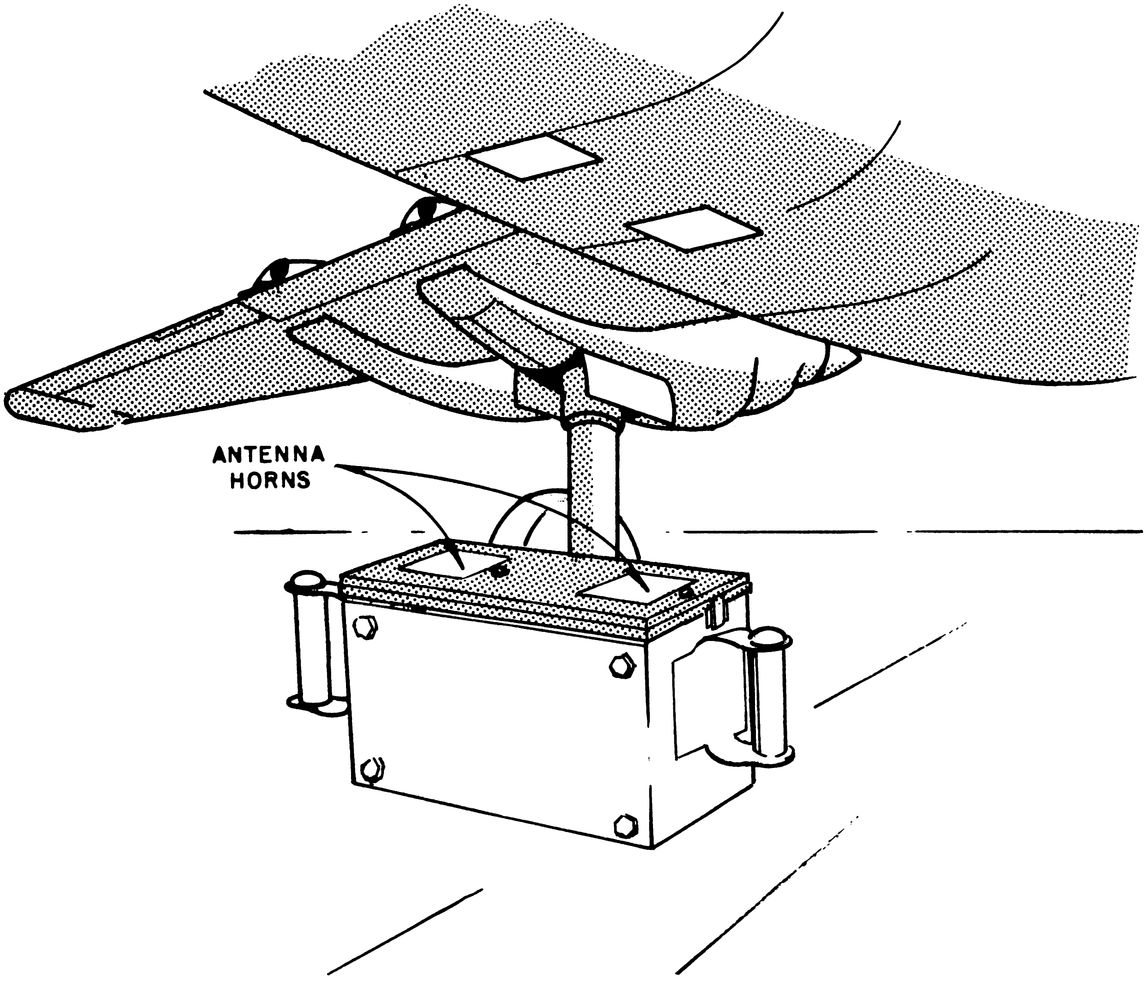

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Figure 8-50.—Delay line MX-1381/APM-66.

TEKTRONIX TYPE 453 OSCILLOSCOPE

The Tektronix Type 453 Oscilloscope is a lightweight, transistorized portable oscilloscope which has high frequency capabilities. The input signal range is from d.c. to 50 MHz. Input power to the scope is either 115 volts a.c. or 230 volts a.c. at line frequencies from 45 to 440 Hz. The power consumption is approximately 100 watts.

Some of the capabilities of the 453 Oscilloscope are as follows:

1. Display of two independent sweep signals simultaneously.
2. Display a signal which has an intensified portion, and this portion is also displayed as a complete separate sweep.
3. Various-time measurements.
4. Peak-to-peak signal measurements.
5. Voltage measurements of any point of a signal.
6. Voltage comparisons.
7. Frequency measurements.
8. Phase difference measurements.
9. Rejection of unwanted signals.

CHAPTER 9

ELECTRONIC PRINCIPLES

This chapter is intended to provide an introduction to some of the more important topics and principles of electronics which do not fit into any specific chapter of this manual. In some cases, the information is of a general nature, applicable to many systems or equipments. In other instances, the data are based on relatively new developments and concepts which have not as yet reached the point of general applicability.

MODULATION AND DEMODULATION

Modulation is a process that permits the transmission of intelligence by superimposing it on an RF carrier. The carrier is normally of a constant frequency and amplitude; modulation varies one or more characteristic of the carrier in accordance with the intelligence to be transmitted. The characteristics of the carrier which may be varied are the amplitude, frequency, and phase. The type of modulation is designated by the particular characteristic which is to be varied. Demodulation is a process by which the intelligence is extracted from the transmitted wave and reproduced either in its original form or in some other form.

There are many ways to impose the intelligence on the carrier. In radiotelegraphy the operator depresses a key (switch) which activates the transmitter as long as the key is depressed. In radiotelephony the transmitter is operative as long as the microphone is activated; the sound picked up by the microphone is converted into an electrical signal and superimposed on the carrier. In radar the transmitter is activated automatically and regularly by pulses from the synchronizer. Regardless of the method of modulation, the modulating circuit functions to change the a-c output of the carrier generator in accordance with the instantaneous values of the intelligence signal. The demodulator (detector) must be matched with the system so as to respond to the particular type of modulation used.

MODULATION SYSTEMS

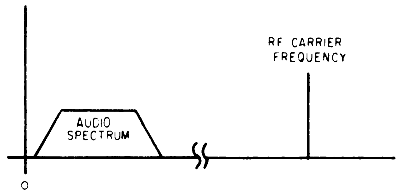
Each type of modulation has its own specific advantages and disadvantages, its own characteristics, and its own applications. In the discussion which follows, several types of modulation are compared.

The original and still the most commonly used type is amplitude modulation. Its major disadvantage is its susceptibility to noise. In order to overcome this disadvantage, frequency modulation is becoming more popular. Closely resembling frequency modulation is the process of phase modulation, a system which is not in common usage.

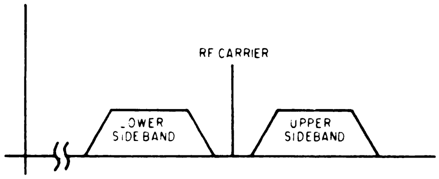
Amplitude Modulation

The RF carrier portion of the amplitude modulated wave is of fixed frequency and constant amplitude. An audiofrequency modulation signal is superimposed on the carrier in a manner that causes the amplitude of the carrier to vary, leaving the carrier frequency unchanged.

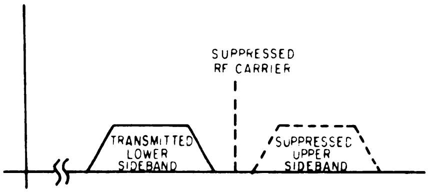
An amplitude modulated wave is composed of a number of frequencies, as shown in figure 9-1 (A) and (B). These frequencies are the carrier, the audio signals, the sum frequencies, and the difference frequencies. In the example, the frequencies are indicated as frequency bands on a spectrum graph because of the complexity of the audio signals, which normally include an enormous number of individual frequencies.



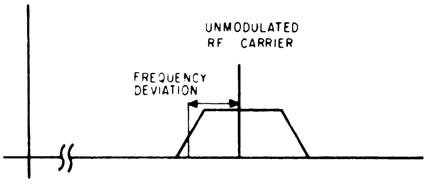
(A) INPUTS



(B) AM SIGNAL



(C) SSB SIGNAL



(D) FM SIGNAL

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Figure 9-1.—Signal spectrum, comparison.

The sum and difference frequencies are known as the sidebands, and carry the intelligence. When an RF carrier is modulated by a voice signal or by music, the side frequencies constitute a band of frequencies above (the sum) and below (the difference) the carrier. The width of each band is determined by the highest and lowest frequencies included in the modulating signal. The overall bandwidth required in the transmitter and the receiver is determined by the difference between the low end of the lower sideband and the high end of the upper side band. As each sideband contains identical infromation, the sidebands are redundant with only one sideband and the carrier being needed in AM detection.

Single Sideband

Single sideband has proved to be a more efficient and reliable means of voice communications, than has amplitude modulation. Efficiency has been improved by the concentration of the entire transmitter RF output into a single frequency spectrum rather than the division of power by the AM transmitter into a lower sideband, a carrier, and an upper sideband. This division of power in an AM transmitter results in less RF energy available at the AM receiver for detection of the modulated audio than would be available at an SSB receiver if a single sideband transmitter were being used.

In a single sideband system, the audio spectrum is mixed with an RF carrier in a balanced mixer. The output of the balanced mixer contains the carrier frequency minus the audio signal (lower sideband, LSB) and the carrier frequency plus the audiofrequency (upper sideband, USB). The design of the balanced mixer is such that the carrier frequency is suppressed. The output of the balanced mixer is applied to a mechanical filter which passes only one sideband. The output of the mechanical filter is essentially the audiofrequency translated up to the carrier frequency, plus or minus the audiofrequency. (See fig. 9-1 (C).) Transmitter and receiver bandpass is determined by the upper and lower limits of the sideband transmitted.

The sideband is thus heterodyned up to the desired operating frequency, amplified in the transmitter power amplifier, and fed to an antenna. Sideband power applied to the antenna is greater with single sideband than with AM because all transmitted power is contained within a single sideband. (Either sideband may be used.)

To receive a single sideband signal, it is necessary to translate the signal back to the original audiofrequency intelligence signals. The carrier frequency, which was removed at the transmitter prior to radiation, is generated locally at the receiver and mixed with the received sideband signal. The result of this mixing is the original audio signal, which is subsequently separated from the RF in the detector.

Frequency Modulation

In frequency modulation the carrier amplitude remains constant and the output frequency of the transmitter is made to vary about the carrier (or rest) frequency at a rate corresponding to the audiofrequencies of the intelligence signals.

The extent to which the frequency changes in either direction from the unmodulated carrier frequency is called the frequency deviation (fig. 9-1 (D)). It corresponds to the change of signal amplitude in AM.

In frequency modulation systems there is no "percentage of modulation" to correspond with that of AM systems. The frequency deviation is dependent on the design of the specified equipment and is only indirectly determined by the modulating signal.

The ratio of the maximum frequency deviation to the audiofrequency of the modulating signal is called the modulation index, or deviation ratio. Allowable frequency deviation is determined by the frequency separation of adjacent channels, and this maximum deviation and the frequencies involved in the intelligence signals combine to determine the maximum modulation index.

Phase Modulation

In phase modulation, the instantaneous phase relationship between the modulated signal and the unmodulated carrier is varied. During a change in phase the instantaneous frequency of the signal also changes, so that the two methods (phase and frequency) are quite similar. Identical receivers may be used to receive either phase modulated or frequency modulated transmissions. Since phase variations are essentially equivalent to frequency variations, phase modulators are commonly used to develop FM signals.

Although the end result is essentially the same, phase modulation has the advantage that the carrier frequency can be stabilized (for example, with a crystal oscillator), while in FM the RF must be permitted to change in frequency during modulation.

Frequency-Shift Keying

Transmissions used in radioteletype, facsimile, and some data link equipments utilize a modulating system known as frequency-shift keying. In this equipment a keyer replaces the oscillator of a conventional CW transmitter. The keyer supplies a source of RF excitation that can be shifted slightly either up or down (or both) in order to make a distinction between pulses and spaces.

During unmodulated (continuous wave transmission) frequency-shift operation, the transmitter operates with a specified carrier frequency. When a MARK on a PULSE is to be transmitted, the transmitter frequency is shifted slightly (usually downward). In the three-level type operation (which is not in common usage at present), the frequency is shifted in one direction for a digital ONE, in the opposite direction (by the same frequency deviation) to represent a ZERO.

HETERODYNING

Heterodyning is a process by which two or more frequencies are combined in a nonlinear device so as to develop a composite output. In a heterodyne circuit (mixer) the frequencies involved are the original input frequencies, the sum frequency, and the difference frequency. (The modulation systems thus far discussed involve heterodyning action.) A nonlinear device is required to provide the mixing action; in a linear device, no mixing takes place.

Heterodyning is also involved in the creation of the intermediate frequency in receivers. In this application, the incoming modulated signal is mixed with the constant frequency out of the local oscillator. The result is the IF.

PULSE MODULATION

An example of pulse modulation systems is the conventional radar set. A pulse of short time duration is developed in a synchronizer, and is used to trigger the transmitter. The transmitter operates for the duration of the pulse input, and then rests until the next input once again serves to trigger it into operation. This intermittent operation of the transmitter permits the transmission of relatively large values of power for short times (peak power), while allowing a long rest period to keep the average power within the limitations of the equipment.

Pulse modulation is also employed in the operation of computers and in digital data transmission systems. These topics are developed in some detail in various chapters of this manual; the current discussion is intended primarily to present some details regarding the pulses involved in the systems. (In connection with the discussion, make frequent reference to fig. 9-2.)

The main characteristics of a pulse are based on time, general shape, and magnitude of voltage or current change. For purposes of this discussion, the pulse is assumed to be a theoretical square wave of positive-going voltage. (This is the type pulse most commonly used in radar modulators, as well as in digital data systems, computers, etc.) It is further assumed that all actions are initiated by a trigger pulse which occurs at a TIME ZERO reference.

Since the pulse represents a change of voltage level, some passage of time is required for this change to occur. Although this elapsed time is undesirable in most applications, it is unavoidable. For purposes of this analysis, the pulse may be divided into three parts: leading edge, top, and trailing edge. Normally it is desired that the leading and trailing edges be as sharp as possible, and that the top be flat. The terms used in the discussion and indicated on figure 9-2 are fairly well standardized in pulse applications. Each time increment gives a direct indication of the quality of operation of the circuitry involved in the use or generation of these pulses.

Pulse Duration and Magnitude

The duration of a pulse is normally considered to be the time interval between the 50 percent points in the rise and fall of voltage levels. (Some references use the 90 percent points for this consideration.)

The magnitude of a pulse is the difference in voltage level between the maximum (signal) state and the minimum (quiescent) state.

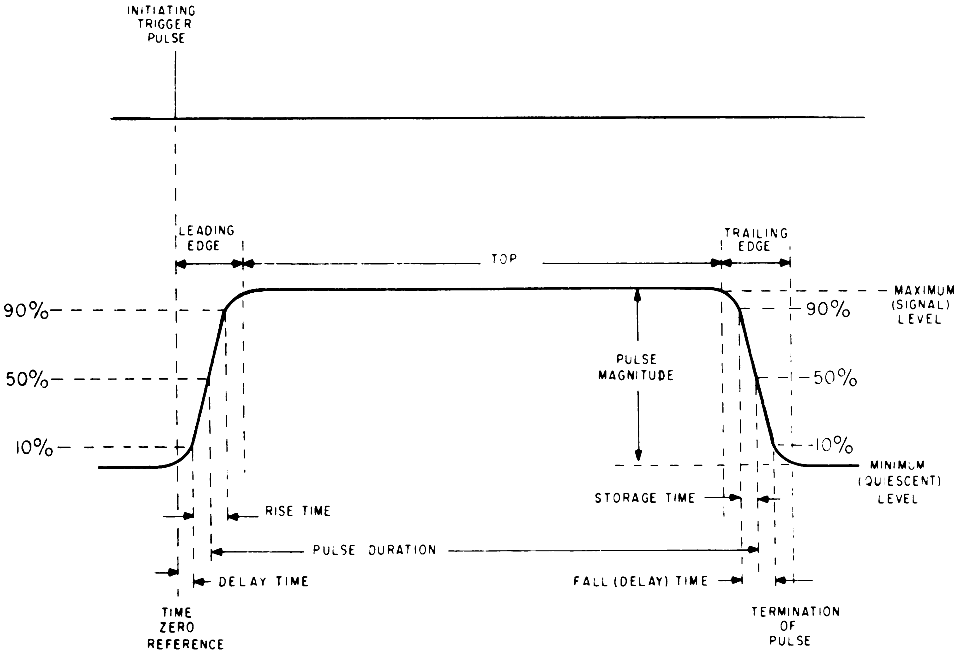

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Figure 9-2.—Pulse characteristics.

Leading Edge

The leading edge of a pulse is that portion which represents the increase of voltage from the quiescent level to the stabilized maximum level. In some pulses there is some overshoot and revovery (not shown in fig. 9-2); these increments are included in the leading edge.

Following the initiating action of the trigger pulse, the voltage level begins to rise. The DELAY TIME represents the period required for the pulse to reach 10 percent of its ultimate magnitude. Until the 10 percent value is reached, it is assumed that the pulse amplitude is not sufficient to perform its normal functions. Delay time is the result of the time required for the active components of the circuit (transistors or vacuum tubes) to switch from one state to the other.

The RISE TIME represents the period required for the pulse to increase from 10 to 90 percent of its ultimate magnitude. This increment is normally associated with the charging of lumped or distributed capacitances or the building of magnetic fields within various circuit components. In practical waveform analysis this is the period usually used to describe the steepness of the leading edge of the waveform.

Once the pulse has reached 90 percent of its ultimate magnitude, it is considered to be fully capable of performing all the functions required of the pulse.

Trailing Edge

The trailing edge of a pulse represents the return of voltage from the stable operating level to the stable quiescent level. It includes any overshoot and recovery which may be present.

In computer work, the interval during which the pulse decreases from 90 to 50 percent of its maximum value is referred to as the STORAGE TIME. It is during this time that the pulse is usually routed to the memory unit.

The FALL TIME (or the DECAY TIME) denotes the period during which the pulse voltage decreases from 90 to 10 percent of its maximum value. It includes storage time. The fall time interval is normally used to evaluate the quality of the trailing edge.

Once the pulse has decreased to the 10 percent level, it is considered incapable of performing its assigned functions.

Pulse Top

The pulse top refers to that portion during which the voltage level remains relatively constant at its high signal value. The term may be used to refer to the pulse segment falling between the 90 percent voltage points. More commonly, however, it is used to refer to the portion between the first attainment of maximum voltage level to the beginning of the rapid decline in voltage.

In most pulses, once the voltage has reached its maximum level, it tends to decrease slightly during the "flat" portion. The longer the pulse duration, the more drastic this deterioration usually becomes. The deterioration is frequently the result of capacitor charge leakage. Whatever the cause, in radar transmitters this decrease in voltage level of the modulator pulse may result in a change in the operating frequency and/or the output power of the magnetron.

PULSE-TIME MODULATION

Pulse-time modulation is a refinement of the pulse modulation technique. In pulse modulation, the transmitter is keyed or triggered; in pulse-time modulation, this triggering is encoded in some manner involving time. In this system the timing of the pulse is part of the intelligence to be conveyed, and compatible pulse-time circuitry is required to extract the intelligence from the wave.

An example of pulse-time modulation is the TACAN system (discussed in some detail in chapter 17 of this manual.) In this system, the transmitter sends out a comparatively large number of pulses, most of which are meaningless. The only pulses which convey intelligence are those with a definite time relationship to each other. A receiver which does not have a compatible decoding circuit would be incapable of demodulating the signal and using the information.

Digital computers and data transmission systems use a somewhat different version of pulse-time modulation. In these equipments, the coding is accomplished by converting the intelligence into binary form and routed as a pulse or no-pulse train.

In both examples, the timing of the pulses conveys an integral part of the intelligence, but the methods and meanings are different. In the TACAN system, randomly-spaced pulses constitute most of the transmitted signal; in digital work the pulse and no-pulse intervals are evenly spaced and controlled by "clock pulses."

DEMODULATION

As mentioned previously, a nonlinear device is required to modulate a carrier frequency. A nonlinear device is also required to demodulate that carrier in order to extract the intelligence from it. Detectors, crystal mixers, discriminators, and coincidence gates are examples of circuits used as demodulating devices.

Demodulation is a process by which the intelligence superimposed on the carrier is removed and reconverted into the original modulating signal.

ELECTROMAGNETIC RADIATION

A general discussion of wave motion is presented in chapter 5 of this manual. Basic Electronics contains a basic discussion of the radiation of electromagnetic waves. Certain aspects of radio waves, especially those applicable to radio direction finding equipment, are discussed briefly in chapter 17 of this manual.

The current discussion of electromagnetic wave radiation is intended as a brief summary of the data contained in those sources. It is also an expansion of some specific topics dealing with the general subject. The discussion is limited primarily to radio waves, and includes general characteristics, propagation principles and methods, and polarization techniques.

CHARACTERISTICS

Electromagnetic waves are complex waves. They consist of two mutually perpendicular fields—electric and magnetic. They travel at a relatively constant velocity of 300,000,000 meters per second in space, and at a slightly different velocity in other media. They tend to travel in a theoretically straight line in a direction which is mutually perpendicular to the two component fields. They are, however, subject to reflection, refraction, diffraction, and absorption (with or without reradiation).

The frequency spectrum of electromagnetic waves extends from somewhat below 30 kHz upward to some unspecified limit. The usable spectrum is being extended in both directions as new developments occur. The spectrum includes those frequencies generally called radio waves, heat, infrared, light, ultraviolet, X-rays, etc. Each broad division of the spectrum possesses easily distinguishable characteristics as well as characteristics common to all electromagnetic waves.

Figure 9-3 is an illustration of the spectrum of electromagnetic wave radiation, with the broad limits of each band designated. The limits of the band are more or less arbitrarily chosen for convenience—there is no sharp division between adjacent bands.

PROPAGATION

As discussed in Basic Electricity, NavPers 10086-B, an electric current flowing in a wire sets up a magnetic field about that wire. If the current is alternating, the magnetic field will expand and collapse, reversing direction in synchronism with the current which produced it. If this alternating magnetic field cuts a wire, it will produce an alternating current in that wire.

The principles of the radiation of electromagnetic energy are based on the laws that a moving electric field creates a magnetic field, and a moving magnetic field creates an electric field. The created field is always in time phase with its parent field, but it is perpendicular to it in space. These laws hold true whether a conductor is present or not.

In systems making use of electromagnetic waves in the radiofrequency spectrum, an antenna is used to convert electric current into fields for transmission, and to convert fields into electric current during reception. Basically, an antenna is a conductor or a system of conductors which serves to radiate or to intercept waves of electromagnetic energy. Basic theory of operation of antennas is discussed in Basic Electronics, and a discussion of several major types of antennas may be found in chapter 11 of this manual.

POLARIZATION

Polarization of an electromagnetic wave is the directional characteristic of the electric and magnetic fields of the wave. In general usage, the electric field is used as the reference. The polarization phenomenon is found throughout the entire range of known electromagnetic radiations.

The type and direction of polarization are defined by looking at the polarization vector in the direction of propagation, rather than by looking at the wave as it approaches the observer. Polarization is frequently classified as linear (horizontal or vertical), or circular, depending on the direction of the electric field. In linear polarization the field is considered to maintain a constant direction; in circular polarization it is considered to rotate as it progresses away from the propagating antenna.

As the wave travels through the atmosphere or ionosphere, it is reflected and refracted by particles and other electromagnetic fields. This results in rotation of the polarization from its original state. In addition, a second component appears that follows a different path, with attenuation and phase shift characteristics different from the original wave. The result is an elliptically polarized wave. In recently modified theories, the linear and circular polarization are considered as special cases of an elliptically polarized wave.

Unpolarized Waves

In an unpolarized electromagnetic wave, the electric field appears to have random orientation with respect to the earth's surface. In a plane perpendicular to the direction of propagation, the electric field seems to have approximately equal magnitude in all directions. Radiation from atomic or nuclear processes is normally unpolarized; thus, ultraviolet, visible light, and infrared radiations emanating from heated bodies, electrical discharges, or nuclear agitations are normally unpolarized.

Polarized Waves

In a polarized wave, however, the orientation of the electric field is completely predictable. Electromagnetic waves originating in vacuum tube or transistor oscillators, resonant cavities, etc., are always polarized. The electric vector of the wave may lie in a plane with a constant relationship to the propagation, or the electric field may tend to rotate about the axis of propagation as it travels away from the transmitting antenna.

The initial polarization of a radiated wave is a function of the orientation of the radiating antenna. The shape of the antenna, the distributribution of current and voltage, and the radiation characteristics of the antenna determine the polarization with respect to the antenna. The orientation of the antenna with respect to the surface of the earth then determines the polarization of the wave with respect to the earth.

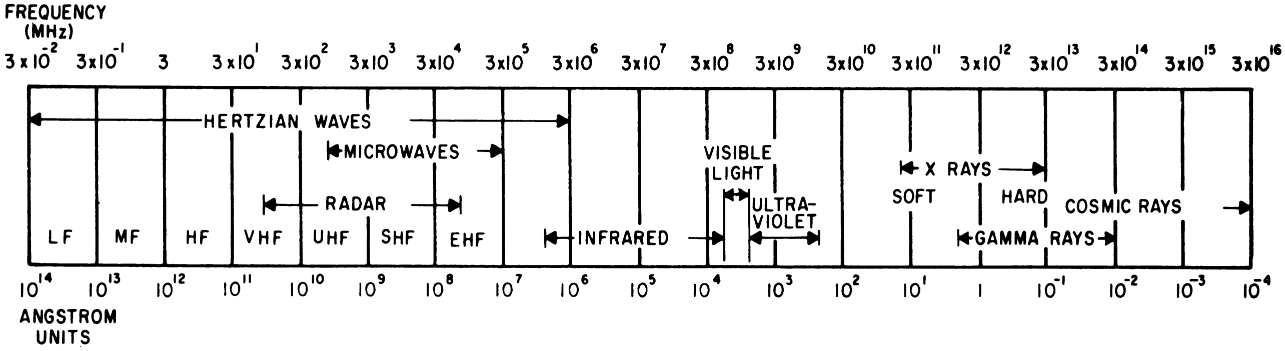

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Figure 9-3.—Spectrum of electromagnetic waves.

Vertical Polarization

An electromagnetic wave cannot be propagated without both the electric and the magnetic fields. A propagated wave has both a groundwave (or direct) component and a skywave (or reflected) component. At frequencies up to about 1500 kHz, the groundwave is generally more useful than the skywave. At the time of transmission, the two components are indistinguishable; the groundwave is simple that portion of the transmitted wave that travels along the surface of the earth and the skywave is that portion that does not. Thus, the polarization of the two components is exactly the same at the time of transmission.

A dipole antenna mounted so that its physical axis is vertical to the earth's surface propagates vertically polarized waves. That is, the electric field is vertical and the magnetic field is horizontal.

The earth's conductivity determines the rate of attenuation of the groundwave. With perfect conductivity no horizontal component of the groundwave could be sustained, because the earth shorts out any horizontal component of the electric field. The earth, however, is an imperfect conductor, so the horizontal component of the electric field in the groundwave is attenuated at a rate depending on the conductivity of the earth in the local area.

With horizontal polarization, this condition results in a proportionately large loss of the signal. With vertical polarization, however, the portion of the wave front traveling along the surface is slightly retarded. This causes the wave front to lean slightly in the direction of propagation; it thus tends to follow the curvature of the earth, extending the range of the groundwave.

At frequencies below 1500 kHz, the groundwave permits the use of vertical polarization for long range communications. At higher frequencies, the groundwave component is more greatly attenuated, with a consequent decrease in maximum effective range obtainable from the groundwave component of the wave front. However, the higher the frequency, the less the wave front tends to lean. Therefore, progressive increase in frequency approaches line-of-sight transmission, rather than following the earth's curvature.

Horizontal Polarization

At higher frequencies (or when skywave operation is desired), horizontal polarization is normally used. This condition permits attenuation of the groundwave, as previously mentioned, but has little effect on the skywave component. Long range coverage is obtained by using the reflective and refractive properties of the ionospheric layers.

At frequencies above about 30 MHz, however, the skywave is not returned to the earth's surface, so the range is decreased considerably and tends toward line-of-sight coverage.

Use of the skywave component creates problems of polarization shift. These problems are discussed later in this section under the heading of elliptical polarization.

Circular Polarization

Circular polarization describes an electromagnetic wave whose electric and magnetic fields rotate about the axis of propagation, maintaining their perpendicular relationship. This rotation is, in effect, similar to the rotating magnetic field of a polyphase a-c motor. Two-phase motors use two alternating currents of the same frequency but with a 90° phase relationship to supply two field windings which are physically oriented at right angles to each other. If the two currents are of the same frequency, equal magnitudes, and 90° phase displacement, the resultant field will rotate in direction and maintain a constant magnitude.

Circular polarization of electromagnetic waves may be obtained through the use of two linearly polarized dipole antennas mounted physically at right angles and supplied driving signals 90° displaced in phase. In actual practice the same signal may be used to excite both antennas, with the phase displacement resulting from use of different lengths of transmission line. If the transmission line to one antenna is effectively a quarter-wavelength longer than the transmission line to the other antenna, proper phasing is obtained.

The resultant wave rotates at the same frequency as the driving signal, and maintains a constant magnitude; it is thus circularly polarized. Direction of rotation is determined by the time sequence of the signals to the separate antennas.

Optimum reception of circularly polarized waves requires the use of a receiving antenna which is circularly polarized in the same direction as the wave. Nonrotation or rotation in the opposite direction results in cancellation of components of the received signal.

One important practical application of the use of circularly polarized waves is found in some search radar equipment. Circular polarization of the radar beam provides the advantage of reduced echo magnitude from rain. This advantage is not obtained without some decrease in returns from other targets. When using circular polarization, rain echoes are reduced by approximately 20 db; however, normal target returns are also reduced—by approximately 3 db. This results in a loss of about 18 percent in usable radar range. Circular polarization should therefore be used only when the radar targets would otherwise be lost in the rain returns.

Elliptical Polarization

A circular wave can be thought of as consisting of two linear waves, as indicated previously. An elliptical wave can similarly be thought of as consisting of two circular waves. An elliptically polarized wave may also be considered as a wave produced by two unbalanced linear waves, as described in the following discussion.

The same elements which were described for the circularly polarized wave may be used to describe the elliptically polarized wave. If the signal applied to one antenna is attenuated as well as delayed, unequal drive and unequal radiation result. Under these conditions rotation still occurs, but the magnitude of the resultant wave is not constant. A graph of the strength of the radiated signal resembles an ellipse. The same condition may be obtained by changing either the physical orientation of the dipole antennas or the phase relationship of the two feed signals.

It has been mentioned that all electromagnetic waves may be considered to have elliptical polarization, with linear and circular polarization being merely special cases. It has also been stated that the use of the reflective and refractive properties of the ionosphere introduced polarization shifts and rotations that may offer problems. The following paragraphs discuss these topics.

Assume a wave which is polarized perfectly horizontal with respect to the earth's surface. Unless the ionosphere is also perfectly horizontal and of perfectly uniform density, the reflection or refraction is nonuniform. The nonuniformity results in the introduction of a second factor which tends to react with the main wave.

The interaction between the original wave and a reflected or refracted wave tends to change the phase relationship of the two wave components. Changing the phase relationship results in some degree of rotation, effectively changing the polarization of the wave in the field of radiation. Thus the wave may be polarized horizontally as it leaves the transmitter antenna, but vertically polarized by the time it reaches the receiving antenna.

In actual practice, the shifting occurs to some degree in all propagated waves. Atmospheric and ionospheric particles and extraneous electromagnetic fields react with the signal wave to produce a constantly changing wave polarization. If the total rotation-producing forces cancel, the resultant wave is linearly polarized; if they are of equal magnitude and proper phasing, circular polarization results.

FREQUENCY

As previously discussed, propagated electromagnetic waves of various frequency ranges exhibit certain characteristics which may not be important at other frequencies. Alternating currents and voltages which are not propagated also exhibit characteristics which are peculiar to the frequencies involved.

EFFECTS OF INCREASING FREQUENCY

At frequencies normally designated as "power" frequencies, circuit components (resistors, capacitors, and inductors) are invariably lumped quantities. That is, the values of the components are considered to be constant, and are relatively easy to calculate. They are based primarily on the physical dimensions of the components themselves, and are not appreciably affected by other circuit elements.

As frequency is progressively increased, however, the apparent values of these components change, and the total effect of the components in the circuit cannot be explained by the lumped values alone. Distributed and stray values of resistance, capacitance, and inductance become relatively large with respect to the lumped values, and must be considered. With increasing frequency, these values become progressively more important in determining overall circuit parameters and circuit operational characteristics.

Distributed properties may be defined as the resistance, capacitance, and inductance spread uniformly along the entire length or area of a circuit element. Stray properties refer to the resistance, capacitance, and inductance which exist between a given circuit element and all other objects and between the circuit element and ground.

For example, a 1/4-inch diameter copper rod 4 inches long, placed in free space where no external influences are present, would possess small but definite values of R, C, and L. If the conductor were cut in half, each part would have exactly half the previous values. In other words, the distributed properties are uniform as long as the conductor itself remains uniform in cross sectional size, shape, and conductivity, and provided that no external influences exist. If the conductor is not uniform, the distributed properties still exist, but their distribution is not entirely uniform.

If the conductor is placed in an actual circuit, it retains these distributed properties, and it also acquires stray properties because of its closeness to other components in the circuit. These stray and distributed properties exist in all conductors and conducting elements. They even exist in lumped property components and in the leads. At power frequencies, the distributed and stray values are so small compared to the lumped values that they may be conveniently ignored. In fact, it is usually practical to ignore these values at frequencies up to about 30 MHz, except in such circuit elements as self-resonant sections of transmission lines and antennas.

At frequencies above about 30 MHz, however, distributed and stray values may become so large (compared to the lumped values) that they can no longer be ignored. This happens because of a double-ended change which takes place in circuit elements. On the one hand, increasing the frequency of operation usually requires smaller values of lumped properties. On the other hand, increasing the frequency results in greater interaction between each circuit element and the other components in the circuit. In addition, the actual values of R, C, and L contained in a given component are not constant—they tend to change when frequency is varied. The following paragraphs discuss the changes which occur, and the effects of these changes on circuit operation.

Inductance

The term "distributed inductance" refers to the self-inductance distributed along the length of any type of conductor, whether it is or is not meant to act as an inductor. Inductance, as defined in Basic Electricity, NavPers 10086-B, is the property of a conductor that tends to oppose any change of electron flow (current) through the conductor. Inductance reveals itself only when current is varying in the conductor; a back emf (electromotive force) is induced in a direction that tends to oppose the change in current flow. Even a very short section of straight wire possesses self inductance. The conductor does not have to be wire, however; it can be any conductor, any shape or size.

Usually, the actual amount of self-inductance is small, but its effect becomes important at frequencies above 30 MHz. The effect may be desirable or unwanted, but it cannot be ignored. A complex equation is needed to find the actual value of self-inductance, but the important point here is that the value depends directly on the number of lines of flux surrounding the conductor. Self-inductance is highest at the center of any conductor carrying alternating current, and tapers off toward the outside surface. This is the cause of skin effect, explained later.

UNDESIRABLE EFFECTS.—The property of distributed inductance can cause serious RF losses if leads and connecting linkages are not kept as short as possible. Figure 9-4 demonstrates how this loss takes place. The plate tank circuit (A) is designed to operate at a frequency of 4 MHz. The inductor is connected to the tube plate by a wire having a self-inductance of approximately 0.1 microhenry (μh).

Ignoring loading and other factors, calculation shows that the resistive impedance offered by the tank circuit at reasonance is 4,710 ohms, where the inductive reactance ($X_L = 2\pi fL$) of the connecting wire is approximately 2 ohms, and is so small in proportion to 4,710 ohms that it can be neglected at this low frequency.

When the operating frequency is raised to 100 MHz (fig. 9-4 (B)), the inductance of the tank coil must be reduced to resonate at the higher frequency. At 100 MHz, the self-inductance has decreased slightly but the increase in frequency raises the inductive reactance of the plate lead to 59.6 ohms. The resistive impedance of the tank circuit is still 4,710 ohms at resonance. A voltage divider effect occurs, which prevents the entire RF signal output of the tube from being impressed across the tank circuit and results in a loss of gain. In addition, the introduction of an inductive component causes a phase lag that is undesirable in certain applications. At higher frequencies, the effect becomes even more pronounced, introducing larger losses.

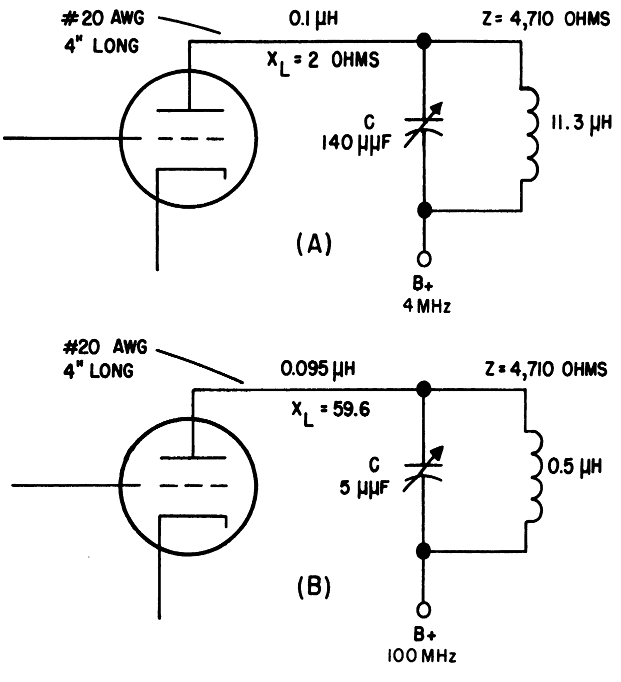

Figure 9-4.—Inductance at high frequencies.

DESIRABLE EFFECTS.—In certain circuits, a condition of series or parallel resonance is desired, and the property of distributed inductance, distributed capacitance, or a combination of both, may be used to achieve this. For example, to provide a bypass for signal voltages from the low-impedance end of an IF tank circuit back to the cathode of the tube, a series resonant circuit offers the lowest impedance path. When the IF is above 30 MHz, it is possible to get the effect of series resonance by cutting the leads of the capacitor to lengths offering the necessary series inductance. This is shown in figure 9-5 (A). Note that the capacitance is lumped, but the inductance is the distributed inductance of the capacitor leads. (See fig. 9-5 (B).) However, the signal voltage sees a certain value of each property, regardless of whether the properties are lumped, distributed, or any combination thereof.

INDUCTIVE COUPLING.—When a conductor carrying alternating current runs sufficiently close to another conductor, its magnetic field induces an electromotive force in the second conductor, causing a current to flow. This is the effect of mutual or stray inductance.

The study of mutual inductance and coupling at lower frequencies usually is restricted to coils and transformers, but above 30 MHz the effect of coupling between two conductors—even two straight pieces of wire—becomes important. This is true because the amount of coupling or mutual reactance between two inductors increases as the frequency is increased, if the physical relationship remains the same.

Some effects of coupling between distributed inductances are undesirable. For instance, if the grid and plate leads of a single tube amplifier stage are permitted to run close to each other, signal energy from the plate circuit may be coupled back to the grid, causing either regeneration or degeneration. Distributed capacitance also is present, but only the inductive coupling effect is considered at this time. As another example, a current-carrying wire may be too near a tube shield, inducing an emf that causes current to flow in the shield. This current flow through the shield is a power loss that can be supplied only from the current-carrying wire.

When inductive coupling causes circuit imbalance or power loss, it usually is spoken of as stray coupling. The amount or degree of coupling depends directly on the relative positions of the conductors as well as their distance from each other. Figure 9-6 shows the effect of physical position on the degree of coupling. In (A) the coupling is loose, inasmuch as the leads are crossing at right angles, and minimum mutual inductance results. The coupling

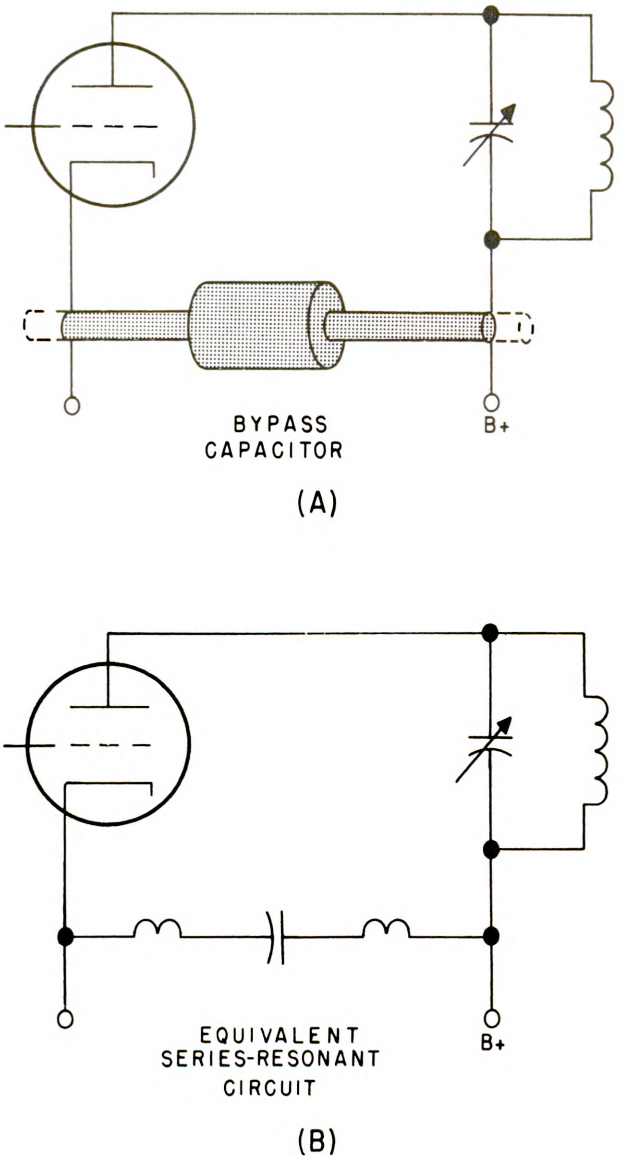

Figure 9-5.–Series self-resonance.

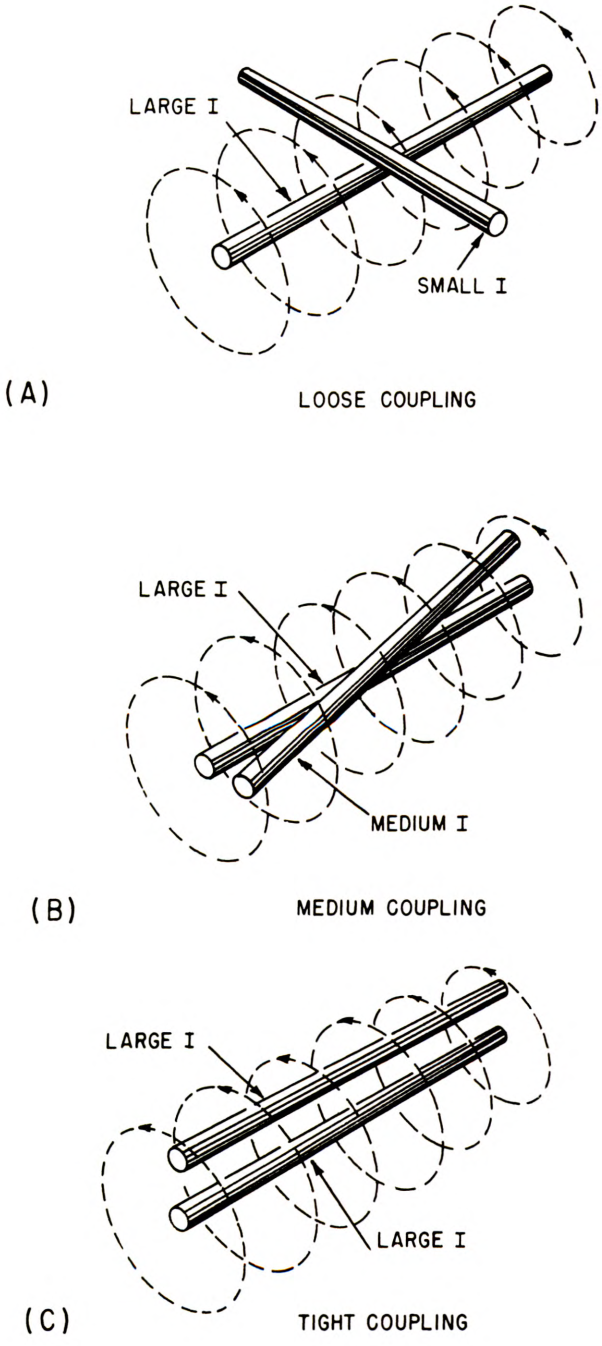

Figure 9-6.–Inductive coupling effects.

between the wires (B) and (C) increases because of the greater amount of mutual inductance. Practical circuits are laid out with the shortest possible leads, well separated from one another, and distant from the chassis and shields. If two wires must cross, they should cross at right angles, because this produces the smallest mutual inductance.

Capacitance

The term "stray capacitance" refers to the capacitance between any point on a conductor and all surrounding objects. Capacitance exists between any two points that are at different electrical potentials. This is true whether the points of different potential are in different conductors or in the same conductor. Although the distributed self-capacitance of a conductor is of relatively little importance, except in special circuits, the effect of the stray capacitance between two conductors must be taken into consideration at higher frequencies. This is because of the capacitance that exists between the parts of circuit elements and the electrodes of electron tubes, as well as between leads and switch contacts.

The actual value of capacitance changes only slightly with frequency, but the reactance changes greatly. The formula for capacitive reactance $\left(X_C = \frac{1}{2\pi fC}\right)$ shows that, if the value of capacitance remains the same, increasing the frequency causes the capacitive reactance to decrease. Therefore, a small value of distributed capacitance at the lower frequencies offers a high reactance to the flow of a.c., but at higher frequencies it offers a lower reactance. This effect is often undesirable when it occurs accidentally between two conductors in a circuit, but may be used deliberately to achieve series or parallel resonance in resonant line sections. The losses in distributed capacitance are lower than those in lumped capacitors because the dielectric is usually air, instead of a solid, and because the RF resistance (discussed later) and distributed inductance values are smaller.

UNDESIRABLE EFFECTS.–An example of the manner in which stray capacitance may upset the proper operation of a circuit is shown in figure 9-7.

Assume that C_d represents a distributed or stray capacitance of 1 $\mu\mu$f appearing between ground and the lead from the coupling capacitor to the grid of tube V2. The stray capacitance C_d effectively shunts the 5,000-ohm grid impedance Zg. If an RF signal at a frequency of 2 MHz is traveling from the tank circuit of V1 to the grid of V2, the 1 $\mu\mu$f distributed capacitance offers a capacitive reactance of 79,618 ohms to the signal. This value is so high in relation to Zg that its effect is negligible at this frequency and similar low frequencies. If, however, a 100 MHz signal voltage is coming from the tank circuit of V1, the same 1 $\mu\mu$f stray capacitance offers only 1,592 ohms of capacitance reactance.

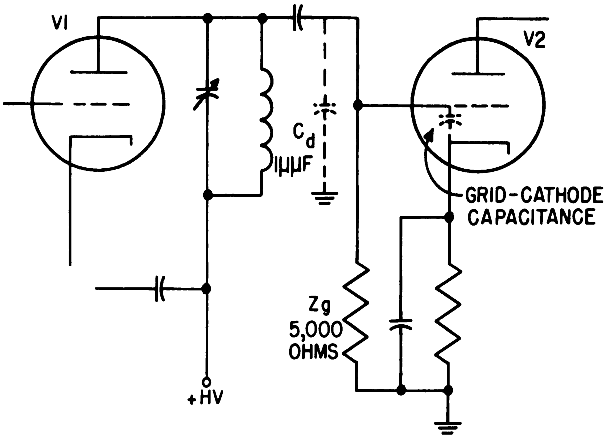

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Figure 9-7.—Capacitance at high frequencies.

Now the signal voltage sees a relatively low impedance path across the stray capacitance, offering less than one-third the opposition of the grid impedance Zg. Therefore, more than two-thirds of the signal voltage is shunted across this path and lost. If the frequency of the signal voltage is increased to 400 MHz, the reactance drops to 398 ohms, and only a very small amount of the signal voltage reaches the grid impedance.

To keep the stray capacitance at a minimum, the circuit wiring is kept well spaced with short leads that run at right angles to one another whenever possible.

DESIRABLE EFFECTS.–For certain applications, such as IF amplification, a parallel LC (inductance-capacitance) circuit, resonant at a single frequency, is useful. A simple way of achieving this is to wind a coil in such a manner that the total (distributed and stray) capacitance is used to make the coil self-resonant at the desired frequency.

Part (A) of figure 9-8 shows the distributed capacitance that exists because of the difference of potential between adjacent turns of any coil. The sum of these small values is shown in part (B) as an effective value of capacitance in parallel with the lumped inductance of the coil. Although most inductors are wound to minimize the distributed capacitance, some are designed to offer the necessary capacitance to provide a desired L/C ratio. This offers an advantage because the response of the tuned circuit can be made sharper than would be possible with lumped-property coils and capacitors.

Resistance

The term "distributed resistance" seldom is used, because it is necessary to distinguish between the resistance offered to d.c. and low frequency a.c. and the resistance offered to RF currents at the higher frequencies.

Depending on the conductivity of the metal or alloy, all conductors have d-c resistance. It is distributed uniformly along conductors that are uniform in cross sectional area, shape, and conductivity. Resistance to RF, however, is caused by d-c resistance plus the effect of self-inductance, which is greater at the center of a conductor than at the surface. At the lower frequencies, this self-inductance has little effect on the flow of current because the values of inductive reactance are extremely small. As the operating frequency increases, the inductive reactance at the center of the conductor becomes higher, and the current seeks the lower reactance path toward the surface, resulting in a current distribution that is not uniform.

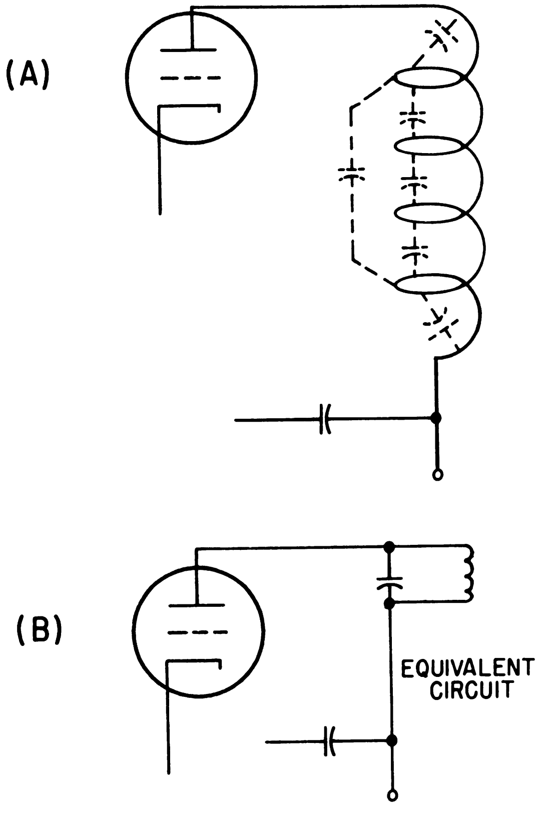

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Figure 9-8.–Parallel self-resonance.

This tendency of the current to flow on or near the surface of a conductor is called SKIN EFFECT. As the frequency increases, less current flows in the center of the conductor and more flows on the surface. The result is that more current is forced through less conductor material, with higher losses and more heating. Because the center of the conductor is not carrying current, the effect is the same as using a smaller conductor. The RF resistance at higher frequencies can amount to several times the d-c resistance of the same conductor.

MINIMIZING SKIN EFFECT.–Skin effect takes place regardless of the shape of the conductor, but it causes less RF resistance in conductors having rectangular cross sections than in those that are circular. Flat copper strips are sometimes used, but are more expensive and not easy to work.

Litz wire, as it commonly is called, is made up of many strands of very fine enameled wire woven together. The current is divided among the strands, and the skin effect on any single conductor is extremely small. Litz wire is comparatively expensive, however, and is not widely used.

Probably the best method of avoiding losses from RF resistance is by silver plating the conductors. This does not eliminate skin effect, but takes advantage of it. When the plated conductor carries RF current, skin effect takes place as usual. Now however, the current is flowing in the silver plating, which has less d-c resistance than ordinary conductors; therefore, the RF resistance is reduced considerably. In practice, plating is expensive, limiting its use.

The most common means of reducing RF resistance is to use a hollow conductor or one of larger diameter. Again, this does not eliminate skin effect. The depth to which the current penetrates is affected only by the frequency and the conductor material; consequently, when the diameter is increased, the current layer has the same thickness but more cross sectional area in which to flow. This reduces the effective RF resistance.

Electrical Losses

As the frequency of operation is raised, the electrical loss in lumped property components increases until a frequency is reached beyond which this increasing loss cannot be tolerated. The increasing loss is, in reality, a combination of three distinct effects—dielectric loss, RF resistance, and radiation loss.

Even in the best dielectric materials, losses increase with frequency. A definite amount of applied energy is lost in each cycle; the more cycles occurring in a specified time, the greater the amount of heat generated in the dielectric.

The RF resistance loss increases with frequency because of increased skin effect.

Radiation loss occurs in any RF circuit. This loss results from direct radiation of energy from individual parts. As long as the circuit element is not more than about one-tenth of a wavelength in any physical dimension, the radiation loss is usually negligble. With increasing frequency, however, it eventually becomes impossible to scale down the physical size of components in proportion to the decrease in wavelength. Losses from radiation increase thereafter. The addition of RF shielding around the circuit decreases the radiation loss, but causes energy to be lost in heating the shield.

The increasing losses which result from increasing frequency reduce circuit efficiency. This factor makes it desirable to use circuit elements and arrangements which have lower built-in losses. As yet it has not been possible to construct lumped property components which do not have some amount of the other properties distributed within them. Increasing the frequency increases the effects of these distributed properties, resulting in increased electrical losses and decreased circuit efficiency.

It has been found practical, however, to take advantage of the stray and distributed properties. Circuit elements and configurations have been designed for operation at high frequencies, using the stray and distributed properties to supplement or to replace lumped components. At the same time, these configurations are designed to decrease the total electrical losses of the circuit. The operating efficiency of these circuits may be greater than that of equivalent circuits using lumped components.

Vacuum Tubes

Although the basic principles of vacuum tube operation remain unchanged, some factors which could be disregarded at low frequencies become important in tube operation at high frequencies. The inductance of electrodes and their leads and the capacitances between electrodes are quite small in absolute value, but at high frequencies their reactances become significant. Skin effect in the electrodes and their leads increases the RF resistance with increases in frequency. Some power is lost due to direct radiation from the electrodes and their leads. Dielectric losses in the insulating electrode supports are also increased. In addition, electrons do not travel instantaneously from cathode to plate, but require TRANSIT TIME. Transit time produces a phase difference between the cathode and plate signals. At sufficiently high frequencies, this phasing can be a considerable portion of a cycle at the operating frequency.

The overall effect of these factors is to reduce tube operating efficiency as the operating frequency is progressively increased. The factors are always present in a vacuum tube, regardless of the operating frequency. As frequency is increased the effects increase and may become so large that they place an upper limit on usable operating frequency. Although it is not necessary to learn new operating principles, it is important to understand the effects of frequency on the operation of tubes and their associated circuits.

CONSTRUCTION FACTORS.—As the wavelength is made shorter, it becomes comparable in length to the physical length and spacing of tube electrodes and leads. The apparent solution to this difficulty is to scale down the entire tube structure. There is a practical limit, however, governed by the power handling capacity required. New tube designs have been developed that successfully overcome one or more of the limitations without requiring a drastic size reduction. For further details on tube design, review chapter 1 of Basic Electronics.

When the tube is cold, the dielectric between electrodes is mostly vacuum. In operation this vacuum is partially filled with a stream of electrons, producing a change in the dielectric constant. The dielectric constant, and therefore the interelectrode capacitance of the tube, changes with variations in the electron stream. The normal capacitance values are measurable, and are listed in tube characteristics tables.

Not only does interelectrode capacitance limit the frequency by establishing a minimum value below which it is impossible to go, but it also varies with the applied voltages and with the loading of the oscillator. This causes frequency instability, particularly when the interelectrode capacitance forms a large part of the tuning capacitance.

TRANSIT TIME.—The effect of transit time is of special concern in connection with the input impedance of the tube. The signal applied to the grid causes a change in the density of the flow of electrons past the control grid. This in turn, causes a current to be induced into the grid. The induced grid current may flow either into or out of the grid, depending on the relative grid voltage at the time. Part of the current flowing in the grid is the current which charges the grid to plate capacitance. The voltage which produces this current is the vector sum of the input voltage (grid to cathode) and the output voltage (across the plate load).

Grid current may flow absorbing power from the input signal, even though the grid is always negative. It has the same effect as if a shunt resistance and a shunt capacitance were connected across the grid and cathode terminals of the tube. The loss of signal energy brought about in this manner is the most important effect of transit time, and the loss increases as the frequency increases.

At lower frequencies with a resistive load, the input and output voltages are (for practical purposes) 180° out of phase and add algebraically to determine the charging current for the grid to plate capacitor. This current is 90° out of phase with the input voltage. At higher frequencies, where transit time is an important factor, the plate current lags appreciably behind the input voltage. At these frequencies, the plate voltage is less than 180° out of phase with the input voltage, and the voltage across the capacitor lags the input voltage slightly. As a result, the charging current is no longer 90° out of phase, but now has an in-phase component. The in-phase current results in power being consumed in the grid circuit. The consumption of power is effectively the same as adding a high resistance between the grid and cathode, with the resistance decreasing as the frequency is increased.

Transit time effects can be minimized by scalling down tube dimensions or by increasing operating voltages. Amplifiers designed for use above 30 MHz usually have close interelectrode spacing. Many transmitting tube types are very small in proportion to their power ratings, and require cooling by forced air draft.

Screen grid tube types have naturally shorter transit time than triodes, and are used in many equipments to reduce transit time effects.

MISCELLANEOUS EFFECTS.—Other effects on electron tubes at the higher frequencies are caused by grid gas current, grid emission, and heat radiation.

In any electron tube there are always some molecules of gas, because it is impossible to produce a perfect vacuum. When electrons collide with these molecules, positive ions are created and are attracted to the negative control grid. This causes a grid current to flow when the grid is negative. The grid current thus produced is small but has the effect of making the grid less negative, which is undesirable in view of the effects of input resistance in this frequency range.

Any metal emits electrons if heated sufficiently, although some are much more efficient in this respect than others. In miniature tubes suitable for use at frequencies higher than 30 MHz, the grid is heated because of its nearness to the cathode as well as by the in-phase grid currents. Some electrons strike the grid even though it is negative, with the possibility of secondary emission. As a result, there is a possibility of both primary and secondary emissions from the grid. This adds to the space charge and is undesirable because it varies erratically.

FREQUENCY BANDS

The radiofrequency portion of the electromagnetic spectrum (designated "Hertzian waves" in figure 9-3) extends from approximately 30 kHz to approximately 3,000 GHz. As previously discussed, both propagated and nonpropagated waves exhibit characteristics which depend on frequency. As a matter of convenience, this part of the spectrum is broken down into "bands" of frequencies. Peculiar characteristics of radio waves are then described in terms of the frequency bands in which they occur.

It must be remembered that there is no sharp division between frequencies at which these changes occur. Rather, the changes occur gradually, becoming more or less pronounced as the operating frequency shifts in one direction or the other. When a peculiarity is attributed to a band of frequencies, the designated limits of the band should be considered as falling somewhere near the center of a transitional range of frequencies through which the change occurs.

As an example of the previous statement, the upper limit at which radio signals can be returned effectively to the earth's surface from the ionosphere is considered to be about 30 MHz. For this reason 30 MHz was chosen as the lower frequency limit of the VHF band (fig. 9-3); HF and lower frequencies are considered capable of reflection, while all higher frequencies are considered limited to direct transmission (line of sight). In actual practice, this 30-MHz dividing line is not an abrupt one. There is no abrupt change in the ability of the ionosphere to return waves to the earth as the operating frequency is increased or decreased. The change in the behavior of the ionosphere takes place over a wide region of the frequency spectrum, with the region centering about 30 MHz. The point of highest reflectible frequency may be considerably higher or lower at any given time under given conditions.

The 300-MHz dividing line between the VHF and UHF bands and the 3,000-MHz upper limit of the UHF band are also more or less arbitrary figures, agreed upon for convenience. They do not represent sharp divisions, but rather as the approximate center point of transitional region.

Transmitters and receivers installed in naval aircraft are frequently classified as VHF or UHF equipment. In practice, these equipments usually cover only a portion of the designated band. VHF equipments normally cover frequencies between 115 and 156 MHz. UHF equipments usually operate from 225 to 400 MHz. Although this frequency range includes the upper portion of the VHF band, the equipments are designated as UHF.

CHARACTERISTICS OF VHF AND UHF

The outstanding characteristic of propagated waves in the VHF and UHF bands is its line-of-sight limitation. As previously stated, these frequencies are not usually returned to earth from the ionosphere. Even in the VHF band, however, sporadic ionospheric reflections occasionally permit long-range use of these waves. Since sporadic conditions are not consistent and predictable, ordinary usage of this band is limited to line-of-sight operations.

The outstanding characteristics of electronic equipment designed to operate in these bands are noted in the size of components and in the use of stray and distributed properties of L, C, and R to supplement the properties of lumped components.

In VHF equipments, the L, C, and R are usually lumped components. Due to the frequencies involved, the required values of L and C are smaller than those required at lower frequencies. This factor permits use of inductors which consist of only a few turns of wire—the high frequency permits even this small value of inductance to produce the high reactance required. The high frequency also permits use of capacitors with smaller plate areas.

In circuit design the stray and distributed properties of L and C and the a-c resistance are taken into consideration, and these factors are then used to supplement the lumped values. In maintenance procedures, it is important to avoid excessive movement of components or wiring, since this movement affects the stray inductance and capacitance of the circuit.

The use of small series resistors to suppress parasitic oscillation (undesired resonance within a stage due to the effects of stray

L and C) is common in VHF and UHF equipment. Also common in these circuits is the use of coiled interconnecting leads to introduce inductance into d-c and low frequency a-c signal paths. With normal operating conditions, this small inductance has neglible effect, so signal characteristics are not affected. High frequency signals are, however, present within the equipment, and these signals are coupled (through stray L and C) into low-frequency leads. The large inductive reactance which is produced by these signals prevents the introduction of large magnitudes of high frequency signals into the low frequency circuit.

Tubes used in VHF equipment are usually of the miniature or subminiature type, to take advantage of the low interelectrode capacitance and decreased transit time.

Components used in UHF circuits carry the same efforts even further. Parasitic suppression is accomplished in the same manner as in VHF circuits. Frequent use of series inductors and shunt capacitors in d-c leads is an additional filtering method designed to keep RF signals out of the d-c supply. In many circuits the lumped L and C components are completely eliminated, and resonance is achieved through distributed and stray values alone. Where "lumped" components are still used, they often consist of a looped wire—a half-turn "coil" may comprise the resonant tank.

Hollow (tubular) conductors, mounted parallel to each other and connected by a sliding capacitor or shorting bar (for tuning) are frequently used as the resonant tank in medium and high power oscillators and amplifiers. Other such stages make use of special tubes built with the tube elements internally connected to concentric cylinders.

Transmission lines for VHF and UHF equipment are usually coaxial cables, but in the upper part of the UHF range, some use is made of waveguide.

MICROWAVE CHARACTERISTICS

Microwave circuits are characterized by the almost complete absence of lumped inductance and capacitance; maximum use is made of the distributed propeties of conductors. Tank circuits usually consist of resonant cavities, with klystrons and magnetrons supplying the required power. The transmission line is almost invariably waveguide in high power circuits, although coaxial cable is sometimes used to transfer low signal magnitudes.

Within the microwave circuit, signal transfer is usually accomplished in the form of electromagnetic waves rather than as voltage or current variations. This method of signal transfer practically eliminates the effect of a-c resistance, which could be excessive at these frequencies.

Input and output impedances and the selection of alternate signal paths are controlled by the use of waveguide sections. These sections are built or adjusted to the proper length so as to supply the desired impedance, from open circuit to short circuit. By selecting specific methods of coupling or by changing the contours of the inside of the waveguide, it is possible to control signal magnitudes and to determine the reactive component of the signal.

The basic components of microwave systems are discussed individually in chapter 11 of this manual. Brief discussions of the overall operation of specific microwave systems appear in chapter 18.

MICROELECTRONICS

The Naval Air Systems Command uses the term MICROELECTRONICS to refer to those processes and techniques involved in the construction of circuits in a relatively small, nonseparable form. Active elements such as transistors, and passive elements such as resistors and capacitors are closely integrated on a single wafer or block to form a functional circuit.

Microelectronics includes the construction technique referred to as integrated circuitry; it also includes the use of thin-film techniques; and, in some cases, it includes the use of discrete microcomponents (for example, a transistor made separately and then added to an assembled unit). The term is not used to include construction using miniature (but otherwise conventional components with interconnecting wiring between the individual components, even though some wiring may be required between assemblies in microelectric construction.

MICROMINIATURIZATION, on the other hand, is a term generally having a broader meaning. This term is used to refer to all efforts directed toward making electronic devices as small as possible. The Army's micromodular construction technique, for example, is excluded from the NavAir concept of microelectronics, although it represents a good example of microminiaturization. The micromodule consists of tiny wafers of insulating material, on each of which is mounted an electronic element such as a diode, capacitor, transistor or resistor. These elements, some the size of pinheads, are connected by wire threads. Micromodules represent the last practical step in the process of miniaturizing conventional electronic devices. Hundreds of thousands of such elements can be crammed into a cubic foot of space. Microelectronic devices are even smaller than micromodules.

PURPOSES OF MINIATURIZATION

In conventional circuits, electrical connections are the cause of numerous failures. As electronic systems become more complex, the increase in the number of parts used and of the connections between them decreases the potential reliability of the circuitry. A characteristic of microelectronic devices which is even more important than their small size is the drastic reduction in the number of soldered connections required. Using a single block of semiconductor material, it is possible to fabricate complete functional subassemblies which require connections only for inputs and outputs from the assembly.

The major objective of the microelectronics trend is to develop building blocks, with each block capable of performing the function of a complete circuit or group of circuits. With this capability, the block should then have one or more of the following characteristics:

1. Perform more electronic functions per unit of volume, weight, cost, power input, and power dissipated than is possible with even the most advanced components and circuit assembly techniques currently available.
2. Possess considerably higher reliability than their conventional counterparts.
3. Require a minimum of maintenance as a result of improved reliability.
4. Achieve low unit cost, making throwaway maintenance practices economically practicable.
5. Perform certain new functions which are not possible with presently available components.

Size reduction alone is not always the aim of microelectronics; small size is inherent in the technology. Although the size and weight reductions are highly significant, in some applications they do not justify the development of an entirely new system of fabrication.

Trouble isolation to a module rather than a specific component part reduces the number of items to be checked, and thus decreases maintenance time. The requirement of increased reliability at reduced cost is inherent in this form of maintenance. By mechanizing production and improving processing techniques, the initial cost can be drastically reduced; by auto matic system checkout techniques, trouble isolation can be made almost completely automatic.

CLASSES OF COMPONENTS

The conventional circuit with normal or miniature components will continue to be used. Some components such as the magnetron and high power-consuming devices do not, at present, lend themselves to drastic size reduction. Miniature components, although they do not compare with thin-film or solidstate integrated circuitry in size reduction, will also continue to be used in military applications. Unfortunately, only a limited selection of miniature components, modules, and packaged assemblies is available. It is estimated that 25 to 30 percent of all military needs for electronic circuits will continue to be filled for years to come by normal or miniature components.

This discussion describes the various classes of microminiature components now being used, reviews a few of the present applications, and notes some of the problems yet to be solved in the microelectronic techniques.

Discrete Components

In reducing weight and bulk, the microminiature component goes one step farther than the miniature component. Capacitors, resistors, transistors, and diodes are currently being used in conjunction with passive thin films. By micropackaging techniques, size and weight reduction is realized, but the connection into usable circuits is a time-consuming and tedious operation, and the soldered connections do not realize full reliability potential.

Hybrid Circuits

Hybrid circuits using thin-film subassemblies of passive elements to which the active elements are attached represent the next logical step in fabrication. The number of soldered connections is reduced and the number of wafers is also decreased. Thus, this method is a slightly improved example of microminiaturization which is sometimes included in the definition of microelectronics.

Thin-Film Devices

Thin-film microelectronic devices consist of passive elements (currently limited to resistors, capacitors, and small inductors) on substrates of glass, ceramic, steatite, or other suitable insulating material. All active elements, and some passive elements, are added to the circuit as discrete components.

Solidstate Integrated Circuits

Solidstate integrated circuits represent an extension of silicon transistor technology. These circuits derive their name from the fact that the circuit is formed in a single block of silicon semiconductor material. They contain both active and passive circuit elements interconnected with deposited metal patterns. The selection of circuits fabricated on the solidstate principle is at present the limiting factor in utilization of the solidstate module. Considerable development emphasis is being given to this limiting factor.

TECHNIQUES

There is a difference between microelectronics and micropackaging. The latter generally refers to the assembly of discrete, miniaturized components within a single enclosure and electrically connected by wires and deposited films. This technique is similar to conventional methods in that separate, discrete components are used. The individual component cases or enclosures may, however, be removed and the individual components bonded to a common substrate and interconnected, with the complete subassembly then hermetically sealed in a single package. The individual components must be individually processed, handled, and interconnected. This decreases the reliability of the assembly, and increases the unit cost. It does, however, approach the size and weight reduction of microelectronic circuits.

In the true microelectronic technology, all the equivalent components (active and passive) are fabricated in one continuous operation on an entire block of material. The components need never be handled as individual items, and all connections except input to and output from the circuit are an integral part of the block. This technique maximizes reliability because of the lack of separate interconnections within the individual module. Computer-controlled automatic processing techniques will standardize construction and reduce unit cost of producing the modules, making throwaway maintenance economically practicable.

Actual production and manufacturing techniques presently in use are summarized briefly in the following paragraphs.

Deposited Film Technique

This technique involves the fabrication of circuits which are composed of thin films of metallic or semiconductor material deposited on substrates. The individual elements of these circuits cannot be disconnected from each other.

Several methods are used to deposit the film. The most commonly used method consists of evaporating a metallic or dielectric material in a high vacuum and condensing the vapor onto a thin inactive wafer. Carefully prepared masks control the areas exposed for deposition. By successive steps of depositing metallic or dielectric films, resistors, capacitors, and conductors can be deposited onto a single wafer. (Note that reference is made to the conventional types of components as used in the part. The differences are that there are no leads between components, and that circuit interconnections are an inherent part of the process.)

Other methods used to deposit the film include the oxidation of certain metals, thermal decomposition of gaseous compounds, and "sputtering." In the oxidation process, the metal is first deposited onto the substrate, and a specified section is then oxidized to obtain special characteristics. In thermal decomposition, extremely close tolerances are required in the masking, purity of the compound, temperature, and exposure time.

Some materials have extremely high melting temperatures and are therefore almost impossible to deposit by the evaporation technique. For these materials, the sputtering technique has been developed. In this process, the material is boiled under extreme heat in a high vacuum, and then deposited in small droplets onto the substrate wafer.

Silk Screen Technique

In this process, a mixture of special sand and fluxes is applied to a ceramic substrate and then the unit is fired (in a manner similar to the ceramic painting and glazing process). Prior to firing, interconnections are screened on, using metallic "inks"; external connections are welded, brazed, wire-bonded, or soldered after firing. Use of the silk screen technique results in a film of considerably greater thickness than that of the thin-film technique.

Semiconductor Growth

This technique is the one most commonly used in the production of solidstate circuits. The process begins with a single bulk-form block of semiconductor material as the substrate. Impurities are alloyed or diffused into the material to form PN junctions. (The semiconductor material itself is used in the formation of resistors and capacitors.)

In most cases the elements themselves and their interconnections are integral parts of the semiconductor substrate; differentiation between the elements and the substrate becomes vague. Internal interconnections are reduced by designing one element to begin where another ends.

MANUFACTURING PROCESS. —The manufacturing process consists of a number of steps using silicon dioxide masks to control the doping of the semiconductor material. By use of computer-controlled equipment, the original block of semiconductor material is progressively masked, doped, oxidized, etched, and otherwise processed to form junctions which possess the desired characteristics. Thus a single block of material may contain the equivalent of various combinations of transistors, diodes, resistors, capacitors, and interconnecting wires, with areas provided for connecting leads for input signals, power, and output signals.

CHARACTERISTICS. —The performance of solidstate circuits is limited by the capacitance of the back-biased junctions between the silicon substrate and the N-type islands in which the circuit elements are diffused. This parasitic capacitance has been a limiting factor in obtaining good high frequency response.

Resistance and capacitance values are somewhat more limited in solidstate circuits than they are in thin-film networks, and inductance is as yet unattainable. Circuit resistor tolerances of closer than 20 percent are difficult to attain. Temperature coefficients are relatively large for all components. Capacitors have low values of Q, are polarity-restrictive, and have comparatively low voltage breakdown values.

The absence of interconnections in completely integrated circuits should lead to greatly improved reliability, simplified maintenance practices, and shorter "downtime" losses.

Power capabilities are limited by the drift in circuit characteristics caused by internally generated circuit heat. Power dissipation is therefore greatly restricted.

APPLICATIONS

Microminiaturized and microelectronic circuits and components are appearing in virtually all new equipments. It is expected that microcomponents and microcircuits will eventually replace about 75 percent of those in present use. However, there are some specific applications especially well suited for their usage.

In chapters (15 through 20) numerous equipments are discussed. Many of these equipments indicate that the module is the basic functional unit, or that the module is the smallest maintainable item. Equipments involved in automatic data processing, logical computations, sequential switching, or precise navigation are currently being designed as integral parts of an overall weapon system—and they are being designed with microcircuit techniques. Another area particularly well suited for miniature and microcircuits is the survival transceiver packed in the liferaft of ejections seats.

PRINTED CIRCUITS

This type circuit appears more and more in electronic equipment, and has proven itself to be equal in operation to conventional type construction. A few simple machine operations automatically produce circuits that formerly required a production line of workers performing the same jobs by hand.

One method of manufacturing a printed circuit is the "photoetching" process. A plastic or phenolic sheet with a thin layer of copper coating may be used. The copper coating is covered with a light-sensitive enamel, and a template of the circuit that will ultimately appear on the plastic sheet is placed over it. The entire sheet is then exposed to light. The area of the copper that is exposed reacts to the light. This area is then removed by an etching process. The exposure of the printed circuit is similar to a photographic exposure. The enamel on the unexposed circuit protects the unexposed copper from the etching bath that removes the exposed copper. After the etching bath, the enamel is removed from the printed circuit. This leaves the surfaces in a condition for soldering parts and connections.

BOOK CIRCUITS

Figure 9-9 shows an improved type of construction, from the troubleshooter's standpoint, consisting of a removable subassembly of the type called "books." These books are readily removable and have numerous internal and external test points to facilitate troubleshooting. The books are built of easily replaceable standard parts. Most test racks have plug extensions that permit any book to be raised, making all parts accessible for checking and repairing. The book is not expendable, but can be easily repaired since all parts are of conventional design. Miniature and subminiature parts are so common in today's electronic equipment that they are now considered to be conventional.

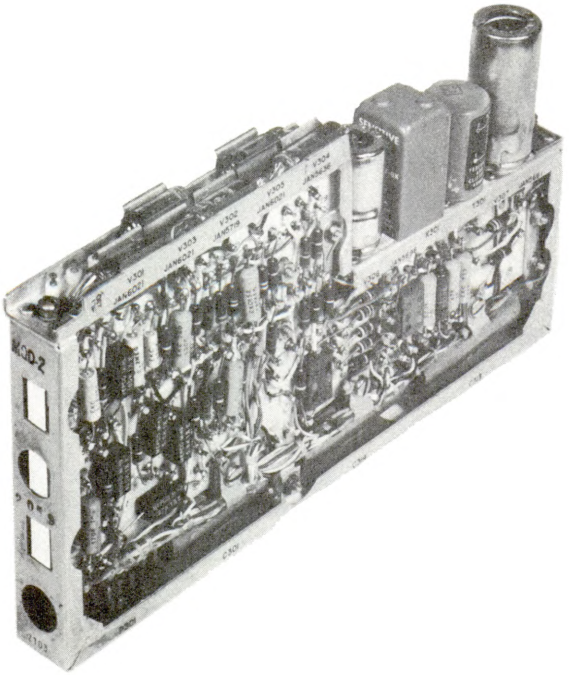

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Figure 9-9.—Electronic "book" construction.

DOPPLER PRINCIPLE

The topics of waves and motion were discussed separately in chapter 5 of this manual. The Doppler principle involves the effect of motion on a wave which has been generated and propagated. This effect is based on the fact that all waves, once they have been propagated into space or into a conducting medium, travel at a velocity which is independent of the wave source. The effect was first noted in connection with sound waves; it has subsequently been observed throughout the entire frequency spectrum. In all cases, a shift in the apparent frequency occurs when the wave source and the detector move toward or away from each other. If the distance separating the source and the detector remains constant, no frequency shift occurs. The present discussion is limited to the implications of this principle in electronic applications.

PRINCIPLE

For this discussion, assume that a wave source is moving in the direction of its propagation. As the source moves, it partially overtakes one wave front before the next is emitted. This has the apparent effect of decreasing the distance between corresponding points on successive waves. (The speed of wave travel is independent of the motion of the source, and need not be considered in the discussion.) The wavelength (as the waves reach a stationary detector located ahead of the source) is shorter than the original frequency would indicate; the detector apparently receives a frequency higher than that propagated. If the source moves in a direction opposite to the direction of propagation, the frequency is decreased in a corresponding manner.

The same effect is noted in the case of a stationary source and a moving detector. In this case, the detector is overtaking part of the wave front, and the time and wavelengths are shortened, and the frequency is apparently increased.

THEORY

This discussion of the Doppler principle is somewhat simplified in order to present the fundamental theory involved. In the explanation that follows, three aspects of a given radar beam are discussed. These are the generated signal wave, the incident wave, and the received wave. The timing of the wave is discussed and illustrated to show how phase shift and frequency shift occur.

An examination of one microsecond of the signal radiated from a CW radar transmitter shows that the signal is composed of many cycles of RF energy. In the time of 1 microsecond, a radar that operates at 13.3 GHz will radiate 13,300 cycles of RF energy, only a few of which are shown in figure 9-10 (A). Each cycle occupies a definite period of time and has a definite physical wavelength. At the frequency mentioned, each cycle occupies 75 micromicroseconds and has a phsycial wavelength of 22.5 millimeters. An expanded view of one cycle of RF energy at 13.3 GHz is shown in (B) of the figure. This cycle will later be shown with one cycle of incident signal superimposed on it to demonstrate expansion due to Doppler effect.

At this point two approaches to explain the effect of signal expansion are used; one involves the action of a cycle of energy as it leaves the antenna, and the other considers the shape of each cycle to be an arc of wave energy. First, consider a single cycle as it leaves the antenna.

The cycle shown in figure 9-10 (B) occupies a certain discrete distance in space and is, in fact, the wavelength of the signal at the frequency shown. When transmitted from a stationary antenna, the leading edge will move out into space 22.5 millimeters by the time the trailing edge leaves the antenna. However, if that cycle is emitted from an antenna pointed aft from a moving aircraft, then the antenna will move a small distance during the time that the cycle is being transmitted. The trailing edge will, therefore, be a greater distance away from the leading edge than it was when the cycle was transmitted from the stationary antenna. This is expansion.

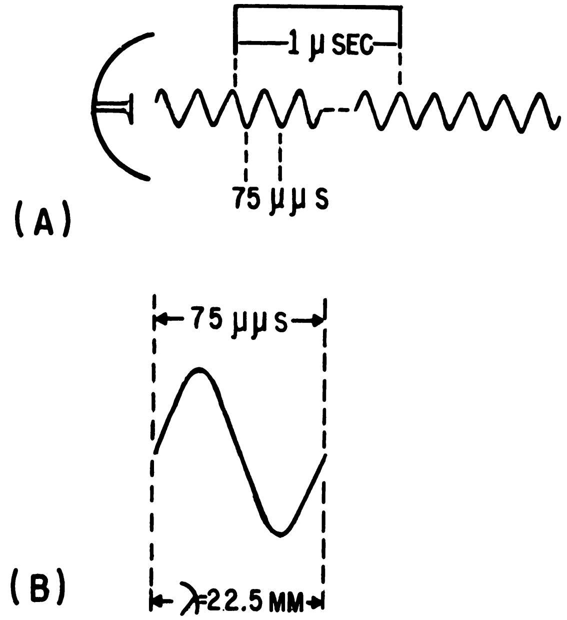

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Figure 9-10.—Examination of a pulse.

Figure 9-11 illustrates this effect and shows, by the dotted line, the space that a cycle would have occupied had the antenna been stationary. Inasmuch as the cycle has been expanded, it occupies more distance in space, the wavelength has been increased, and the frequency has been proportionately decreased. The difference in frequency for this first Doppler shift is proportional to the sine of the radar beam angle multiplied by the ratio of the aircraft velocity to the generated wavelength. In symbols, this would be

$$D.s. = \frac{V}{\lambda} \times \sin \phi$$

When the signal is reflected from the ground and returns to the antenna, a similar expansion occurs. A slightly longer time is required for the cycle to reenter the moving antenna than that would be required if the antenna were stationary. Thus, a double expansion has occurred. This double frequency expansion can be measured by the formula.

$$D.s = \frac{2V}{\lambda} \times \sin \phi$$

The change in frequency is slight, but measurable, and is a direct indication of the speed of the aircraft.

Compression of the signal will result if the antenna is pointed in the forward direction. The explanation is similar to that of expansion except that the leading and trailing edges of the cycle will be closer together (cycle compressed). The effect will be to shorten the wavelength and increase the frequency.

Another approach to compression and expansion is to consider that a CW signal consists of waves of energy radiated from the antenna. Figure 9-12 illustrates the spacing between the waves of a signal from both stationary and moving antennas. The effect is the same as that previously described. The increased spacing (wavelength) between adjacent waves of energy is a direct indication of frequency change. The received signal frequency, when mixed with the generated signal frequency, produces a difference frequency which falls in the audio spectrum. This audio-frequency is a direct indication of the aircraft's speed.

Several specific equipments which make use of the Doppler principle are discussed in some detail in chapter 17 of this manual.

MASERS AND LASERS

The maser (Microwave Amplification by Stimulated Emission of Radiation) is an impor-

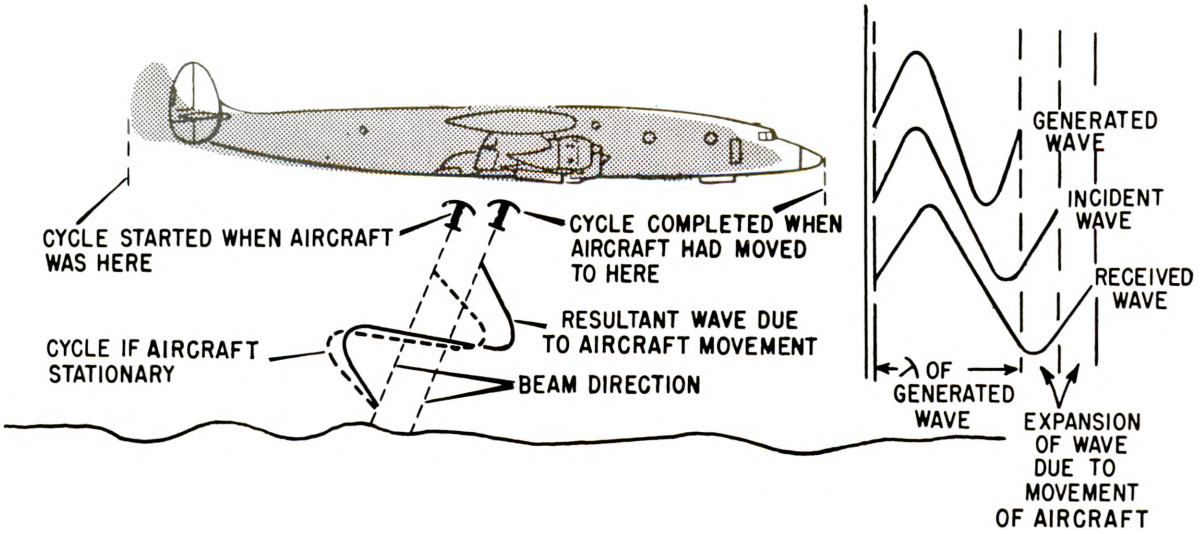
CYCLE STARTED WHEN AIRCRAFT WAS HERE
CYCLE COMPLETED WHEN AIRCRAFT HAD MOVED TO HERE
RESULTANT WAVE DUE TO AIRCRAFT MOVEMENT
CYCLE IF AIRCRAFT STATIONARY
BEAM DIRECTION
GENERATED WAVE
INCIDENT WAVE
RECEIVED WAVE
λ OF GENERATED WAVE
EXPANSION OF WAVE DUE TO MOVEMENT OF AIRCRAFT

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Figure 9-11.–One cycle expansion.

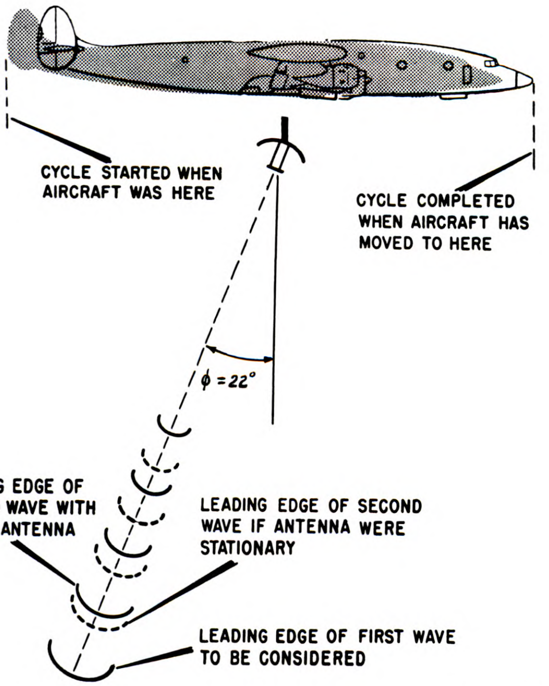
CYCLE STARTED WHEN AIRCRAFT WAS HERE
CYCLE COMPLETED WHEN AIRCRAFT HAS MOVED TO HERE
ϕ = 22°
LEADING EDGE OF SECOND WAVE WITH MOVING ANTENNA
LEADING EDGE OF SECOND WAVE IF ANTENNA WERE STATIONARY
LEADING EDGE OF FIRST WAVE TO BE CONSIDERED

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Figure 9-12.—Energy wave spacing.

tant member of the rapidly growing family of quantum electronic devides. The optical maser, or laser, operates in the visible and near infrared portion of the electromagnetic spectrum.

The feasibility of an optical maser was first suggested in 1958. The first operating laboratory model was constructed in 1960, less than 2 years later. Research, development and application of the laser are currently proceeding at a pace exceeding that of any other device in the history of electronics.

THEORY OF OPERATION

The generation of coherent radiation in the visible region of the electromagnetic spectrum involves interaction of radiation and matter. (See fig. 9-13.) Electromagnetic energy is always absorbed or emitted by an ion or atom in discrete units (photons). For radiation at a given frequency, all photons emitted have energy equal to the product of hf, where $h = 6.624 \times 10^{-27}$ erg sec is Planck's constant, and f = frequency.

A given ion (or atom) can make the transition to a higher energy level by absorbing a photon from the electromagnetic field. It can make a transition to a lower level in either of two ways: spontaneous emission (a random process), or stimulated emission (a coherent process—the phase of the impinging wave is retained in both time and space).

When radiation of the proper frequency enters an area containing ions in thermal equilibrium, it will strike an ion. The ion struck will, if at the upper energy level, transfer to the lower energy level by stimulated emission; but if it is at the lower energy level, it will transfer to the upper level via absorption. Since under equilibrium conditions (fig. 9-14) there are always more ions at the lower energy level than at the higher level, the overall net effect is absorption. If it were possible, however, to begin the operation with more ions in the high energy state than in the low energy state, the reverse would be true. Then entering electromagnetic energy of the correct frequency would cause net stimulated emission, radiation.

Several different techniques for producing population inversion are employed. The method commonly used in solid state lasers is described in terms of ruby, an aluminum oxide containing chromium. The energy levels responsible for the absorption process are shown in figure 9-14. An ion in state 1 absorbs green light and goes to state 3. It rapidly gives up energy in the form of heat and drops to state 2. The mean time that the ion remains at the metastable level, state 2, is on the order of 1 millisecond (about 200 times as long as at state 3); then it spontaneously returns to the ground level by emitting a particular frequency in the red region of the spectrum. If the crystal is illuminated with sufficient green light of the correct wavelength, the population inversion can be maintained. This illumination is commonly termed "pumping."

If the material is properly selected and sufficiently pure, the stimulated emission can be limited to specific frequencies; i.e., frequencies that are known and determined by the physical properties of the elements involved.

LASER OPERATION

The active ion makes a transition from the ground energy level to the pump level when it absorbs energy from the pump sorce. The ideal pump source would emit photons of only the de-

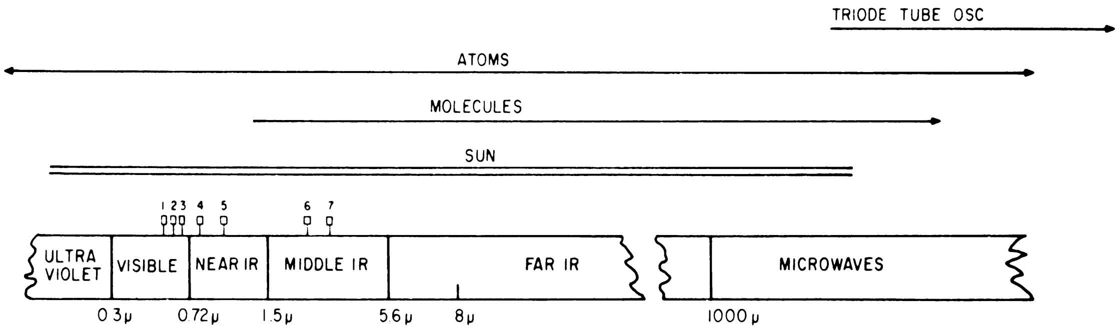

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Figure 9-13.—Spectral range of sources of electromagnetic waves.

sired energy (frequency); however, since such sources are rarely available, it is usually necessary to compromise and use white light. This pump energy could be focused on the laser by sunlight, electronic flashtube, or any other sufficiently intense course.

The ion rapidly falls from the unstable pump band to the metastable level by a photon transition. The metastable level tends to become heavily populated if the pump rate is sufficiently high to put ions into the metastable state faster than they drop back to ground state by spontaneous emission.

After slightly more than half of the ions have been pumped from the ground state to the metastable state (several hundred microseconds for a typical ruby laser), any spontaneously generated light at the correct frequency

($f = \frac{h}{E}$), corresponding to the energy difference

between the ground and metastable energy levels, will cause net stimulated emission. The device will generate coherent electromagnetic energy, coherent light. Because of the design of the equipment, the light generated will be of a given frequency; will have a fixed phase relationship; and will be radiated, parallel to the longitudinal axis through the lightly silvered end of the laser rod.

PRACTICAL REQUIREMENTS

A practical laser device must meet the following requirements:

1. Select a material (gas or solid) which emits light of the desired frequency and is transparent to that frequency. The first gaseous laser, using a helium-neon mixture, emitted light at a wavelength of 1.15 microns (1.15×10^{-6} meters) or 260 terahertz (2.6×10^{14}Hz). The bandwidth spectrum of the emitted light was about 25 kHz because of frequency-pulling caused by mechanical vibration in the structure.

2. Insure adequate purity of the material. Impurities tend to absorb or refract the emitted energy, interfering with the laser action, lowering efficiency and causing unwanted hotspots.

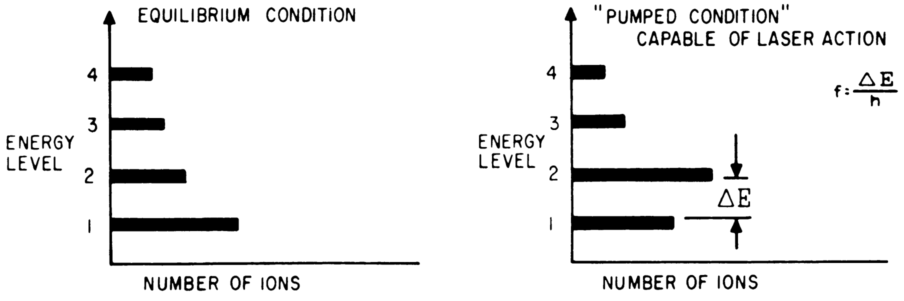

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Figure 9-14.—Energy levels of typical laser materials.

3. Encapsulate the selected material to promote optimum efficiency. Proper design insures maximum coupling or pump energy to the laser. Correct dimensioning insures the maximum level of stimulated emission in the desired direction of propagation.

4. Find an efficient pump source, that is, a source which will maintain the desired energy level inversion with the minimum amount of applied energy. This increases efficiency and decreases heat dissipation problems. The ruby laser has two pump frequency bands, centering on 4100 and 5600 angstroms ($1A = 1 \times 10^{-10}$ meter).

The laser shown in figure 9-15 is refined as follows: a highly pure ruby crystal is grown, machined and polished to a right circular cylinder using techniques developed by transistor technologists. One end is polished optically flat and silvered to become completely reflective to visible frequencies. The other end is also polished optically smooth, but is only partially reflective. The crystal is machined to an exact multiple of the wavelength of the desired operating frequency of the laser; the crystal thus acts as a resonant chamber, continuously reflecting energy along the longitudinal axis. The lightly mirrored end will transmit a portion of the energy which strikes normal (perpendicular) to its surface.

The emitted energy can be focused or otherwise treated in the same manner as ordinary light. It differs from normal light in that it is composed of an extremely narrow band of frequencies and it has a definite spatial phase relationship.

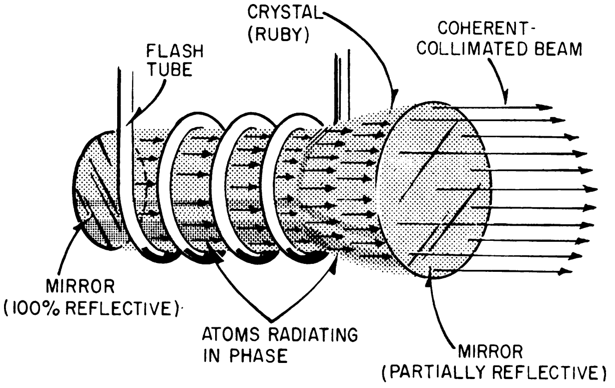

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Figure 9-15.—Simple laser.

APPLICATIONS

It is anticipated that lasers and masers will find extensive applications in many major fields. In view of the known characteristics of masers and lasers, studies are currently conducted to find specific applications in the following fields:

1. Surgical tool. Using a converging lens system, the laser beam can be focused to approach a true point source of light at the focal point. The theoretical limit of the spot diameter would be approximately 1 wavelength (6943 angstroms for the ruby laser). The entire energy radiated could be focused at one spot, creating at that spot a temperature more intense than that at the surface of the sun. This laser beam could be used as a superscalpel, or welding torch, for surgical operations on the human eye and nerves.

2. Communications device. The laser beam can be used as a super-directional communications link in a new uncluttered part of the spectrum. Many researchers are experimenting with methods of modulating the laser beam. One method of modulating the beam with audiofrequencies has already been developed.

3. Energy transfer device. The laser beam constitutes the most intense form of energy propagation yet put at man's disposal. Laboratory models have been used to burn holes through sheet steel. If a sufficiently high-power laser were available, it could radiate sufficient energy from the ground to power satellites or robot helicopters, with practically no energy loss due to transmission.

4. Frequency and distance standard. Since the frequency emitted by a laser depends upon the atomic properties of the material used, the frequency would be known with a high degree of accuracy and would remain constant for the operating life of the laser. The laser will permit all research laboratories to maintain an accurate secondary frequency/distance standard. (1 meter = 1,650,763.73 wavelengths of the orange-red spectral line of krypton 86.)

5. Precision radar system. Lasers have such high spectral purity and directionality that they can be used as precision radar systems. An earth-based laser radar, with an optical system only inches in diameter, has such a high resolution that the beam at the surface of the moon would only be a few miles wide. In a

recent test at the MIT Lincoln Laboratory, the beam of a laser was focused on the moon by a telescope; and returned radiation was detected by a photomultiplier tube after being collected by another telescope. The illuminated area on the surface of the moon was estimated to be 2 miles in diameter.

6. Undersea utilization. Researches are attempting to develop a laser which will operate in the blue-green portion of the visible spectrum. Water is quite transparent at this band of frequencies. A secure undersea communications link or an undersea optical radar has understandably desirable qualities.

In early November 1962, IBM, GE, and Lincoln Laboratory announced simultaneous development of a new laser-a gallium arisinide diode. This new laser has a much higher efficiency potential and far simpler modulation mechanism than its predecessors. It constitutes the next major step forward in laser development. Excited by high current densities (greater than 10,000 amp/cm^2) at its junction, it emits coherent light in the near IR (8400 angstroms) from its polished surface with a beam width on the order of 4 degrees.

The optical laser is destined to become an important segment of the electronics industry. Most high frequency systems (radar, guidance, communications) will employ masers of some type. In the optical region, the laser, only a theory a few years ago, fulfills for the first time the dream of scientists since Newton-a source of coherent light.

CHAPTER 10

ELECTRONIC CIRCUITS

Within any class of electronic equipments there are a large number of identical functions to be performed–and there are usually many different circuit designs used to perform them. Usually no one design is especially better than another. In the interest of standardization, it has been found desirable to concentrate on a few circuit designs for a given function; "preferred circuits" have been selected for standardization and reliability improvement. These circuits have been developed using the latest techniques and fabrication methods. Their use provides maximum flexibility in the performance of specific functions. Economy in parts usage, fabrication costs, and maintenance efforts have been the guiding factors in the adoption of specific circuit designs as the "preferred" circuit.

The preferred circuit configurations and specifications have been made available to all manufacturers of electronic equipment. They are contained in Handbook Preferred Circuits Navy Aeronautical Electronic Equipment, NavWeps 16-1-519 (Series). (Separate volumes are published for vacuum tube and transistorized circuits.) Although use of these circuits is not mandatory in the development of electronic equipments for Navy use, most manufacturers have made extensive use of them.

As a result of the use of these preferred circuits, development of new equipment has become more rapid. Of greater concern to the maintenance technician, however, is the similarity between circuits in different equipments designed to perform identical or similar functions.

Some circuits discussed in this chapter are the standardized preferred circuits. The discussions are necessarily brief; if further information of a general nature concerning a specific type of circuit is needed, Electronics Installation and Maintenance Book, Electronic Circuits, NavShips 0967-000-0120, provides an excellent reference. For the theory of operation of a circuit in a specific equipment, the technical manual applicable to that equipment is recommended.

Several major classes of circuits are not discussed directly in this chapter. Basic Electronics presents basic operating theory of many of these classes. Where that coverage is considered adequate, the circuits are omitted from this discussion.

GENERATING CIRCUITS

Generating circuits, as used in this discussion, refer to those circuits which develop an a-c signal (or a varying d-c level of voltage) as a result of circuit operating characteristics. Signals are broadly classifiable as sinusoidal or nonsinusoidal. Nonsinusoidal signals include square waves, sawtooth waves, pulses, and miscellaneous other types.

Sinusoidal waveform generators comprise the class of electronic circuits called oscillators. A basic discussion of the main types of oscillators is presented in Basic Electronics.

MULTIVIBRATORS

Multivibrators are normally classified as a form of relaxation oscillator. Three basic types are used–astable (free-running), monostable (one-shot), and bistable (flip-flop). The electron tube and transistorized versions of all three types are discussed briefly in Basic Electronics. In the present discussion, three actual circuits are discussed. The first circuit is the preferred electron tube astable multivibrator; the second is the preferred transistorized monostable multivibrator; third is the Schmitt trigger circuit used in many equipments. The Schmitt circuit discussion compares the electron tube and the transistorized versions of the basic circuit.

Multivibrators may be distinguished as to type by the cross-coupling networks between the plates and grids (or between the collectors and bases). In the astable circuit, the cross-coupling networks provide a-c coupling only; the bistable circuit provides d-c coupling for both sections. In the monostable circuit, only one section provides d-c coupling; the other provides a-c coupling only.

Astable PRF Multivibrator

The astable, plate-to-grid coupled multivibrator shown in figure 10-1 is used as a moderately stable repetition-rate generator. It has greater frequency stability than the blocking oscillator and is more economical of components than the Wien bridge oscillator. One disadvantage of the multivibrator is that the output impedance for positive pulses is essentially equal to the plate-load resistance (which must be relatively high for good frequency stability).

The circuit normally uses a miniature or subminiature twin triode and relatively high values of plate-load resistors.

The speed of transition, as in all multivibrators, depends to some extent upon the capacitance between the tube elements, but no special precaution is required in this circuit. The positive-going transition is retarded by the relatively high plate-load resistance and by the timing capacitance, which shunts the output circuit of the tube during turnoff. The negative-going transition is much faster because it is generated at a lower impedance and is slowed only by the output capacitance of the tube and by stray capacitance shunting the

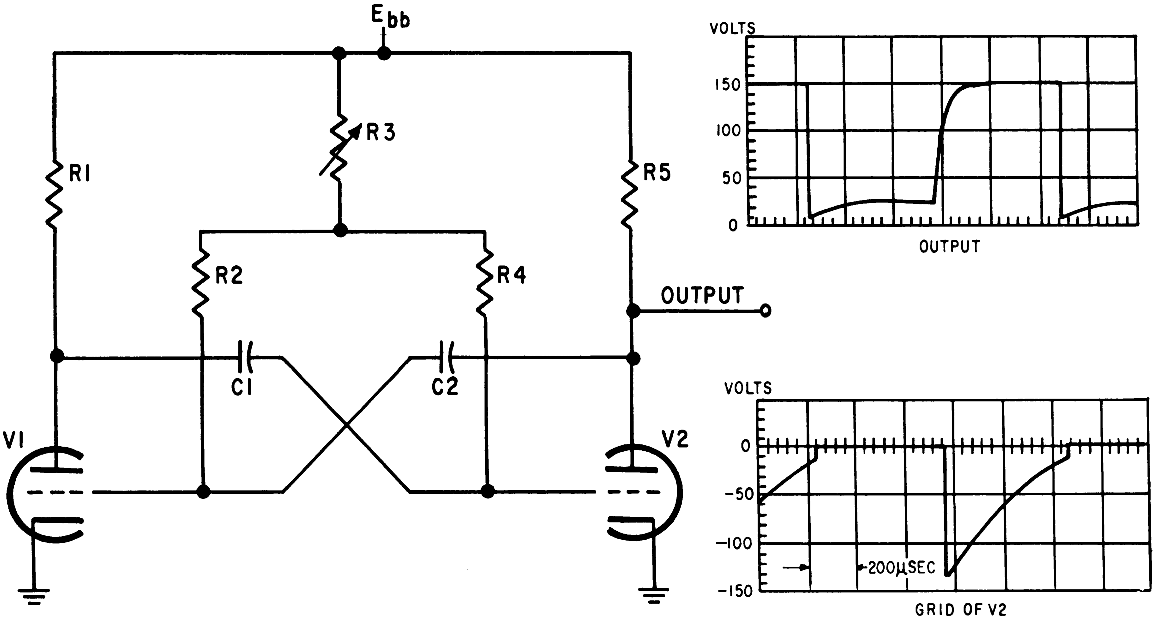

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Figure 10-1.–Astable PRF Multivibrator, preferred circuit diagram and waveforms.

plate circuit. The faster, negative-going transition is recommended as a timing waveform.

The total period of a symmetrical, astable multivibrator with grid resistors returned to a positive voltage may be approximately determined from the equation

$$T = (2RC)\ l_n \frac{E_{bb} + E_o}{E_{bb} + E_c}$$

where T = period in seconds

R = value of either grid resistor in ohms (including the active portion of potentiometer R3)

C = value of cross-coupling capac- (C1 or C2) in farads

E_{bb} = voltage to which grid resistors are returned

E_o = voltage drop across either plate resistor when corresponding tube is conducting

E_c = absolute value of grid cutoff voltage with full plate supply voltage on corresponding plate

l_n = natural logarithm (of the fraction)

The frequency stability of a multivibrator is improved by making the timing waveform on the grid of the cutoff tube very large in amplitude and as steep as possible at the time this voltage is approaching the cutoff voltage. In this circuit a large timing waveform is obtained by using a high resistance in the plate circuit. The full voltage drop across this resistor, when the tube is conducting, is applied to the opposite grid as the timing waveform. This waveform is made steeper by returning the grid resistor to a positive voltage instead of to ground. (The exponentially rising voltage on the grid will then be farther from its final value and will be changing more rapidly as it passes through cutoff.)

The equation for pulse repetition period shows the dependence of the repetition frequency on the grid resistors and cross coupling capacitors. When these components vary, the frequency varies slightly. This variation can be compensated for by adjustment of R3. Periodic adjustment of R3 will also compensate for the variation in repetition frequency caused by tube changes. The potentiometer should be readjusted each time the multivibrator tube is changed.

The output-voltage amplitude varies directly as the plate supply voltage. The frequency change caused by variations in the plate supply voltage is in addition to the frequency changes compensated for by R3.

Monostable Multivibrator

Figure 10-2 shows a transistorized monostable multivibrator. The circuit appears symmetrical except for the cross-coupling networks between collectors and bases. Note that C1 permits a-c coupling only between Q1 and Q2, while R6 permits d-c coupling between Q2 and Q1. Notice that C1 has not been assigned a value. As will be shown later, the value of C1 in conjunction with R3 will determine the time delay that can be obtained.

In this circuit, the transistors are PNP types; Q2 is on and Q1 is off. The base of Q2 is connected to -6 volts through R3, providing forward bias for the emitter-base junction of Q2. Q2 remains in saturation in the absence of external signals; thus it has a low resistance, and its collector voltage is nearly 0 volts. The divider network, consisting of R6 and R2 connected to + 6 volts, makes the base of Q1 slightly positive. Its emitter-base junction is reverse biased and it is in the off condition; Q1 appears to have a high resistance. Diode CR2 clamps the collector of Q1 at -6 volts; CR4 clamps the collector of Q2 to -6 volts when Q2 is turned off. Diode CR1 prevents positive noise pulses (which appear on the -18-volt supply line) from being coupled to the base of Q2.

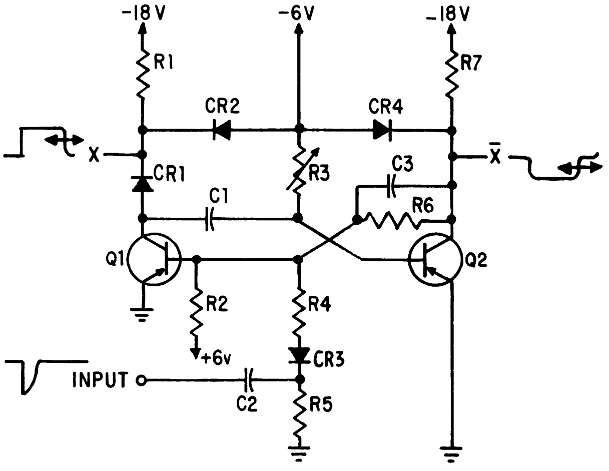

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Figure 10-2.–Monostable multivibrator.

Under these conditions, then, the input required to turn on Q1 is a negative-going pulse with sufficient amplitude and pulse width to insure its starting. The trigger input network consisting of CR3, C2, and R5 comprises an input gate circuit which discriminates against positive signals and passes negative pulses.

A negative input pulse is differentiated in the input RC network, passes through CR3, and drives the base of Q1 negative with respect to ground. Q1 is now forward biased; and a rapid buildup of Q1 collector current occurs, causing the Q1 collector potential to go from -6 volts toward 0 volts. With Q1 in saturation, the left side of C1 is clamped to ground and a +6 volt step is impressed on the base of Q2, causing Q2 to come out of saturation rapidly.

Q2 collector voltage, however, does not fall abruptly since the associated collector load capacitor must discharge. The negative collector voltage of Q2 is applied to the base of Q1 through the divider consisting of R2 and the C3-R6 network, keeping Q1 on.

C1 then begins to discharge through Q1, the power supply, and R3. The voltage at the base of Q2 is changing exponentially from nearly +6 volts to -6 volts. When the base of Q2 goes slightly negative, Q2 conducts again. Q2 collector voltage rises to 0 volts; and the positive-going waveform is applied to the base of Q1. Q1 is turned off; and C1 charges to -6 volts through R1, CR1, and the emitter-base junction of Q2. The circuit is again in its stable state, awaiting the next input trigger pulse.

Circuit delay time is determined by the off time of Q2. Total delay includes the turnon and turnoff delay times of both Q1 and Q2. For delay intervals greater than about 10 μsec, transistor delay times can be considered negligible. The actual time delay varies with changes in R3 and/or C1. These variations are due to the initial tolerances of the components plus the changes caused by temperature and aging. Therefore, R3 is usually made variable and C1 is selected to have a temperature coefficient equal and opposite that of R3.

Schmitt Trigger Circuit

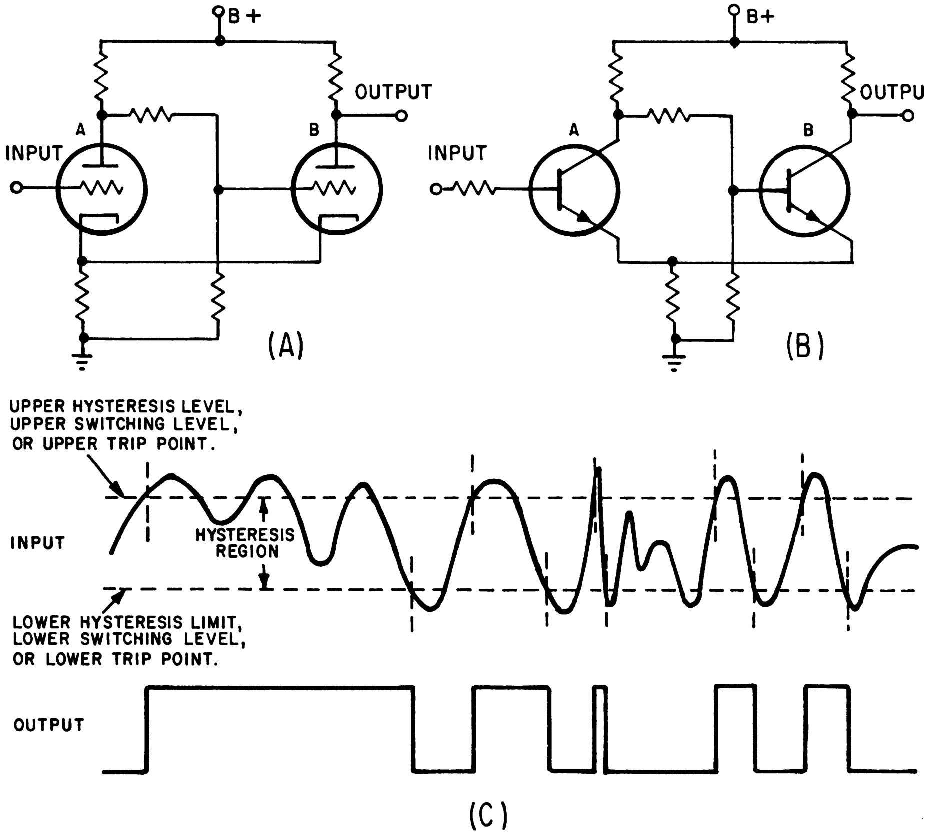
The Schmitt trigger (fig. 10-3) is a bistable multivibrator. It consists of a two-amplifier regenerative circuit which can stay in either of its two stable states indefinitely. In either state, one amplifier is conducting heavily and the other is cut off. The circuit switches states very rapidly on command. The very fast rise and decay times are useful for triggering other circuits. The circuit can also be used as a gate generator, an amplitude comparator, or a "squaring" circuit.

In the vacuum tube Schmitt circuit (fig. 10-3 (A)), amplifier Ais d-c coupled to the grid of amplifier B and the cathode of amplifier B is d-c coupled to the cathode of amplifier A. Cathode-to-cathode coupling is provided by an unbypassed common resistor.

Figure 10-3 (B) shows the transistorized equivalent of the same Schmitt trigger circuit. An output versus input waveform is illustrated in (C). The output curve shown is based on arbitrary operating limits as discussed in the following paragraphs.

The switching from one state to the other occurs when the input rises to a certain level in one case and when the input falls to a certain level for the other case. The region between the two switching levels or trip points is a backlash or hysteresis region. Note in (C) that the input rises to the upper switching level, causes a switching of states, and then varies considerably but has no switching effect until it falls to the lower switching level. This action is somewhat analogous to driving a gear train which has backlash—the gear train input shaft can be turned back and forth indefinitely and no output shaft movement will occur until the backlash has been taken up.

The loop gain of the circuit determines the width of the hysteresis region. For a loop gain of unity, the hysteresis limits coincide; the circuit switches states each time the input passes the single switching level, regardless of the direction of approach. The no-hysteresis Schmitt circuit is seldom used—slight circuit changes could cause the loop gain to become less than unity. With a loop gain less than unity, both amplifiers of the circuit act as fairly linear amplifiers, and no switching occurs. For hysteresis to exist in the circuit, the loop gain must be greater than unity—the greater the loop gain, the wider the hysteresis region.


B+
OUTPUT
A
B
INPUT
(A)
B+
OUTPUT
A
B
INPUT
(B)
UPPER HYSTERESIS LEVEL, UPPER SWITCHING LEVEL, OR UPPER TRIP POINT.
INPUT
HYSTERESIS REGION
LOWER HYSTERESIS LIMIT, LOWER SWITCHING LEVEL, OR LOWER TRIP POINT.
OUTPUT
(C)

AT.155

Figure 10-3.–Schmitt trigger circuits.

BLOCKING OSCILLATORS

The blocking oscillator is another type of relaxation oscillator. It can be free running, synchronized at each cycle or at a submultiple frequency, or it can be driven in the manner of a one-shot multivibrator.

A blocking oscillator is any oscillator which uses the accumulation of a negative charge on the grid capacitor to cut itself off after one or more cycles. Thus, in an oscillator in which the grid swings positive with respect to the cathode, electrons are attracted to the grid and (during charge of the capacitor) accumulate on the plate of the grid capacitor nearest the grid. Since these electrons cannot return to the cathode through the tube during charge of the capacitor, they must return through the grid-to-cathode resistance. If this resistance is sufficiently large, electrons may accumulate on the capacitor faster then they can return to the cathode. A negative charge is thus built up at the grid and may bias the tube beyond cutoff. Once the tube is cut off, no additional electrons are supplied to the grid capacitor. The capacitor then discharges through the resistor, and a point is eventually reached where the tube again conducts. The process is repeated and the tube becomes an intermittent oscillator. The period (rate of the recurrence of operating conditions) is determined by the RC time constant of the grid circuit.

Free-Running

The free-running blocking oscillator is frequently used in radar systems to generate a repetition rate where stability requirements are low. The output can be used as a trigger without additional shaping, but in practice additional shaping is usually incorporated in conjunction with the amplification of the trigger pulse. The major disadvantage of this circuit is its poor frequency stability.

The period of the circuit shown in figure 10-4 is determined by the values of R1, R2, and C1 which comprise the time constant of the discharge circuit. The pulse repetition period is determined by the equation

$$T = (R1 + R2)\ C1\ \log_n \frac{E_i}{E_f}$$

where E_i is the initial voltage across R1+ R2 at the beginning of discharge, and E_f is the final voltage across R1 + R2 at the end of discharge. C1 also contributes to the determination of the pulse width.

Synchronized

The synchronized blocking oscillator is used as the timing oscillator in auxiliary equipment whose timing must be synchronized to that of the radar. Normally, the radar produces its own PRF independently (the PRF oscillator is free-running.) Synchronizing pulses can be introduced at the plate of a blocking oscillator without changing its circuit to vary the PRF. The sync pulse amplitude is such that a predetermined pulse makes the circuit operate. The oscillator may be synchronized on alternate pulses, or on other submultiples, as well as on each pulse. By synchronizing the auxiliary set with the radar, indications can be displayed on the main indicator, relieving the operator of the need to monitor two indicators at the same time.

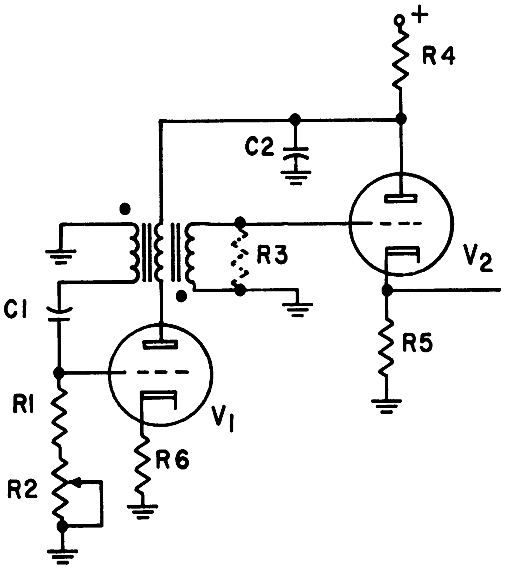


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Figure 10-4.—Free-running blocking oscillator.

The amplitude of the synchronizing pulse has a great effect on the frequency of this circuit. If the amplitude of the synchronization pulse shown is increased, the first pulse after the circuit begins operation brings the grid above cutoff and the circuit is synchronized on every pulse. A lower amplitude pulse could cause triggering on every second or third pulse.

In each case, it is assumed that the natural period of the circuit is longer than the time between the pulses which cause the circuit to operate. If the period of the blocking oscillator is shorter, it produces long and short cycles because the circuit is triggered on some pulses but conducts on its own accord at times.

Driven

Some electronic circuits require a blocking oscillator which operates only when triggered. Such a circuit might be called a BLOCKED OSCILLATOR (since a permanent d-c blocking voltage prevents the circuit from oscillating of its own accord). In this type circuit only a positive voltage on the grid or a negative voltage on the cathode can cause the tube to conduct. If the voltage is a pulse, the circuit goes through a cycle of operation, cuts itself off, and the d-c voltage maintains it below cutoff. Cutoff is maintained by a voltage divider from the plate-supply voltage.

The trigger pulse must be large enough in amplitude to start a cycle of operation. The normal discharge of the grid capacitor reduces the grid voltage after a cycle of operation, but the discharge does not raise the grid bias to the cutoff level, so the circuit does not again conduct without another trigger pulse. The positive trigger pulse is applied to the grid. The output may be taken from the plate, where a large negative pulse is available, or from a third transformer winding where a pulse similar to the plate pulse can be obtained with either polarity.

SWEEP GENERATORS

Sweep generators are used to develop a waveform of voltage which changes level gradually over a period of time. Common uses of this type waveform include CRT sweep and deflection systems, local oscillator AFC tuning systems, certain classes of variable time delay systems, and FM modulating systems. The voltage variation is basically a sawtooth type waveform, but it may be modified to a trapezoidal waveshape for certain applications. It may be generated continuously, or it may be intermittently triggered or gated.

Theory of operation of the basic sawtooth generator is discussed in Basic Electronics. One major disadvantage of that circuit is its inability to generate a linear sweep of voltage. The output voltage wafeform is normally taken across a sweep capacitor; a capacitor always charges exponentially. If only the first 10 percent of the capacitor's charging curve is used, the waveform is considered to have adequate linearity. Under these conditions, the magnitude of the output waveform is small.

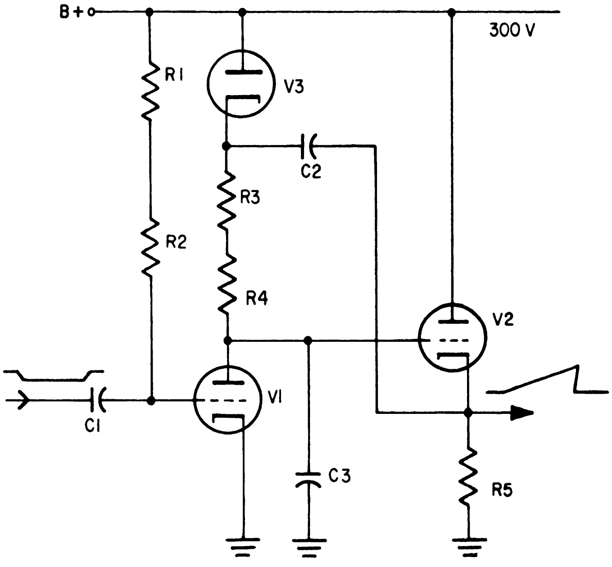
Bootstrap Sweep Generator

The bootstrap sweep generator develops a linear sawtooth of voltage which has relatively large amplitude. The circuit shown in figure 10-5 produces a positive-going voltage rise during the application of a negative-going rectangular pulse.

In this circuit, V1 acts as a switch to control the charge and discharge of timing capacitor C3. The cathode follower, V2, and the bootstrap diode, V3, provide a means for making the charging curve linear instead of exponential.

In the absence of a negative gate, all three tubes are conducting. Most of the B-plus voltage appears across R3 and R4, and capacitor C2 is charged nearly to the B-plus voltage. Timing capacitor C3 is charged only to the low plate potential of V1.

A negative gate input to the grid cuts off V1. The timing capacitor, C3, starts charging through R3 and R4. The rising voltage on C3 is applied to the grid of cathode follower V2. The voltage on C3 and the grid of V2 begins to rise toward the voltage of C2. The cathode current of V2 increases, increasing the voltage drop across R5. This increase of voltage is added to the voltage of C2; the cathode of V3 becomes more positive. Thus the voltage drop remains relatively constant as C3 charges.



AT.157

Figure 10-5.–Bootstrap sweep generator.

With a constant voltage across resistors R3 and R4, the current is constant, and the voltage on C3 rises linearly. The output is taken from the cathode of V2. The bootstrap diode V3 ceases to conduct when the potential of its cathode rises above that of its plate, and effectively disconnects the charging circuit from the B-plus supply. Thus, the voltage of the linear waveform is not limited to the B-plus voltage but continues to rise linearly until the negative gating pulse is removed from the grid of V1. When V1 again begins conducting, C3 discharges to its static low voltage level, and the extra voltage across R5 disappears. Since the cathode of V3 is then slightly less positive than its plate, the tube conducts. The generator remains in this static state until another gating pulse arrives at V1.

Trapezoidal Waveshape Generator

The sawtooth sweep generator is suitable for an electrostatistically deflected CRT. However, most radar sets employ magnetic deflection; sweep voltages are applied to coils. In long range sweeps, the sawtooth voltage is adequate for the desired linearity, but on short ranges, a special sweep voltage with a trapezoidal waveform must be applied to overcome the inductance of the sweep coils. (This topic is discussed later in this chapter.)

A simplified trapezoidal waveshape generator circuit is shown in figure 10-6. The circuit shown is a modification of the sawtooth generator circuit. Note that a resistor, R2, is connected in series with the timing capacitor, C, to ground. The triode serves only as a high speed switch to control the charging and discharging of an RC circuit.

When the tube is cut off (switch opens) by the negative input pulse, the plate voltage rises toward the applied B-plus voltage. The voltage rise is at the rate at which the timing capacitor, C, charges. In an RC circuit, at the first instant of a switching action, the entire voltage present in the circuit is impressed across the resistance; the capacitor charge cannot change instantaneously. However, some of the resistance of the RC circuit (that voltage impressed across R2) is between the plate and ground. This causes a voltage division, and the output voltage (as indicated in fig. 10-6) jumps immediately toward the applied voltage.

The applicable waveforms are shown in figure 10-6 (B). The total of the capacitor voltage plus the sum of the individual resistor voltages always equals the full voltage effectively present in the circuit. The resistive voltage is divided proportionately according to the individual resistances. The curve for R2 voltage is thus a miniature replica of the total resistive voltage.

The output voltage waveform of this circuit is the sum of the R2 voltage and the capacitor voltage. This is the waveform shown in the last graph of figure 10-6 (B), and represents the trapezoidal waveform of voltage required by the electromagnetic deflection sweep coil circuits.

Miller Sweep Generator

In the Miller linear sweep generator (fig. 10-7) the suppressor grid is normally biased negative to prevent plate current flow, while the

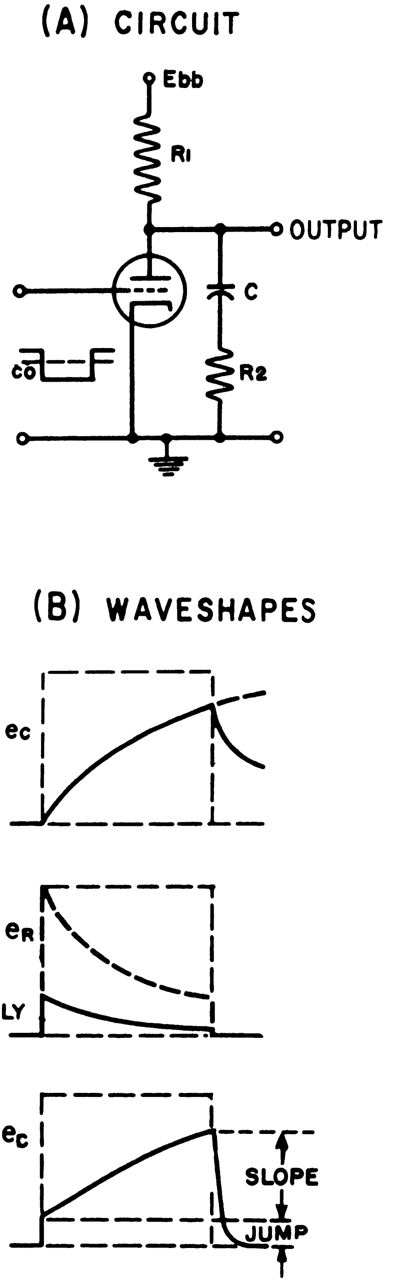


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Figure 10-6.—Trapezoidal sweep generator.

screen conducts heavily. The control grid is returned to B-plus through a resistor so that it is effectively at zero potential, and the cathode is grounded. Observe that the screen is not coupled, that a separate bias source is used for the suppressor, and that an external sweep gate is necessary.

When a positive gate is applied to the suppressor, plate current flows and produces a voltage drop across the plate load resistor. This negative swinging plate voltage is fed back through a small capacitor to the grid, and quickly drives the grid negative. It maintains the plate current at a small value and greatly reduces the screen current.

Reduction of the heavy screen current produces a large positive swing on the screen. The tube remains in this condition, producing a positive screen gate. Meanwhile the plate current (under control of the feedback voltage applied to the grid) flows until no further feedback is produced. During this time the plate current increase is linear, and the plate voltage continues to drop.

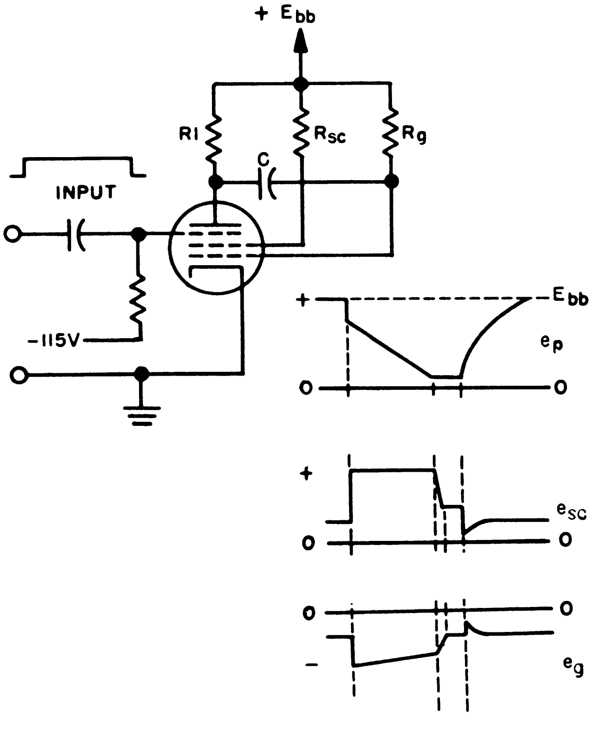

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Figure 10-7.–Miller linear sweep generator.

The normal discharge of C through Rg would cause the current through the tube to increase in an exponential manner, causing the plate voltage to drop exponentially. However, any exponential change is fed back to the grid 180° out of phase with the normal discharge of C, causing a linear increase in plate current.

At a point about 2 volts above ground, no further plate swing is possible. The screen again conducts heavily, returning almost to the initial operating point. When the suppressor gate ends, the plate current is cut off, the screen returns to its initial operating point, and the cycle is ready to be resumed under control of the next gate.

Changing the applied plate voltage determines the point, and the time, at which the plate voltage reaches a minimum (with respect to the leading edge of the input waveform) and the screen resumes control. Changing the values of feedback capacitor C and grid resistor R will also determine the time of operation (by controlling the speed of the grid-plate feedback action).

TIMING AND PULSE GENERATORS

Many avionic systems require accurately timed sequences of operation. Radar systems demand various degrees of accuracy in PRF and pulse width. TACAN and IFF systems depend on pulse-pairs which have specific time intervals between the individual pulses of a pair. Computers and data systems rely on synchronization between clock and data pulses. CRT's are normally blanked during retrace, and the sweep may be delayed for various time increments from the initiation of the overall operating cycle.

Synchronization and time-sequenced operation are usually accomplished through the use of pulses. The time duration of these pulses may be relatively short (trigger) or relatively long (gate). In synchronous operation, the functions may occur simultaneously or one operation may be delayed for some time period from the occurrence of another.

Many of the circuits used in timing and pulse generations are also used for other functions. The present discussion is devoted to brief indications of the functions performed by these circuits, followed by a discussion of the phantastron delay circuit.

Pulse Generation

The use of a sinusoidal waveform in synchronizing a multivibrator is discussed in Basic Electronics, NavPers 10087-B. The sine wave may also be used as the basic source of timing pulses. One such system requires the use of limiters (or overdriven amplifiers), differentiators, sweep voltage counting circuits, and triggered pulse generators.

In the system outlined above, the clippers are used to convert the sine wave to a square wave. The differentiator circuit converts this square wave into voltage spikes. The spikes are then superimposed onto a sweeping voltage waveform to govern the selection of the specific spike to be used in the generation of the delayed pulse.

Relatively short time pulses used for triggers are frequently generated by blocking oscillators. They may, however, be produced by differentiating the output of a multivibrator.

The longer time pulses required for gating are normally produced by multivibrators.

Time Delay

Time delay circuits are utilized when two or more functions must be performed with a specific time relation, but not simultaneously. Such a time relationship may be either fixed or variable. Variable delays may be in multiples of a designated interval, or they may be smoothly variable with no relationship to any specific interval.

Incremental delay circuits normally incorporate a basic generating circuit and a counting circuit. In the synchronized blocking oscillator discussed earlier, operation may be synchronized by an associated sine wave. By proper operation of the blocking oscillator circuit, synchronization may occur on the first, second, third, etc., cycle (of the synchronizing waveform) following the last triggering action. In this system, the blocking oscillator acts as its own counter.

Another type of incremental delay circuit uses a separate counter circuit. In radar range mark systems, an accurate and stable basic generator is used to develop signals corresponding to 1 radar range mile. A counter circuit is then used to produce an output corresponding to 2, 5, 10, etc., miles.

Another circuit which is used to provide a time delay function in electronic equipments is the monostable multivibrator discussed previously. This circuit may be activated simultaneously with the first of the time sequenced operations. Its output is then used to activate another circuit at the instant the multivibrator regains its stable state. The operation of the second circuit is thus delayed with respect to the first. The system time delay is equal to the time duration of the unstable state of the multivibrator.

Phantastron Circuit

The phantastron circuit is a relaxation oscillator similar in operation to the multivibrator. The multivibrator derives its timing waveform from an RC circuit; the phantastron uses a basic Miller type sweep generator. The output waveform of the phantastron is a linear function of the input (control) voltage.

The phantastron is usually triggered on by the leading edge of a gating or trigger pulse, and is shut off by an internally generated waveform. It can also be shut off by the trailing edge of the gate or by a trigger.

Because of its extreme linearity and accuracy, the phantastron output is used as a delayed timing pulse, usually in radar or display equipment. It is also used to produce time-delayed trigger pulses for synchronizing purposes and movable marker signals for display.

SCREEN-COUPLED CIRCUIT.–A typical monostable screen-coupled pentode circuit is shown in figure 10-8. This circuit is started by a positive trigger applied to the suppressor grid, and at the end of operation it returns to the initial starting condition, ready to repeat its cycle of operation when the next trigger arrives.

Three steps are involved in the circuit action–turnon, linear sweep development, and turnoff. The waveforms developed in the tube elements are shown in figure 10-8 (B). Before initiation of action, the circuit is resting with the plate current cut off, due to a negative voltage applied to the suppressor through R3. Resistors R1, R2, and R3 form a combined suppressor and screen grid voltage divider connected between B-plus and C-minus. The values are such that the screen is positive and the suppressor is sufficiently negative to cut off plate current. Since they are directly connected, both elements are d-c coupled; also, through capacitor C1 they are a-c coupled. Therefore, both d-c and a-c voltages appearing on one element also affect the other element.

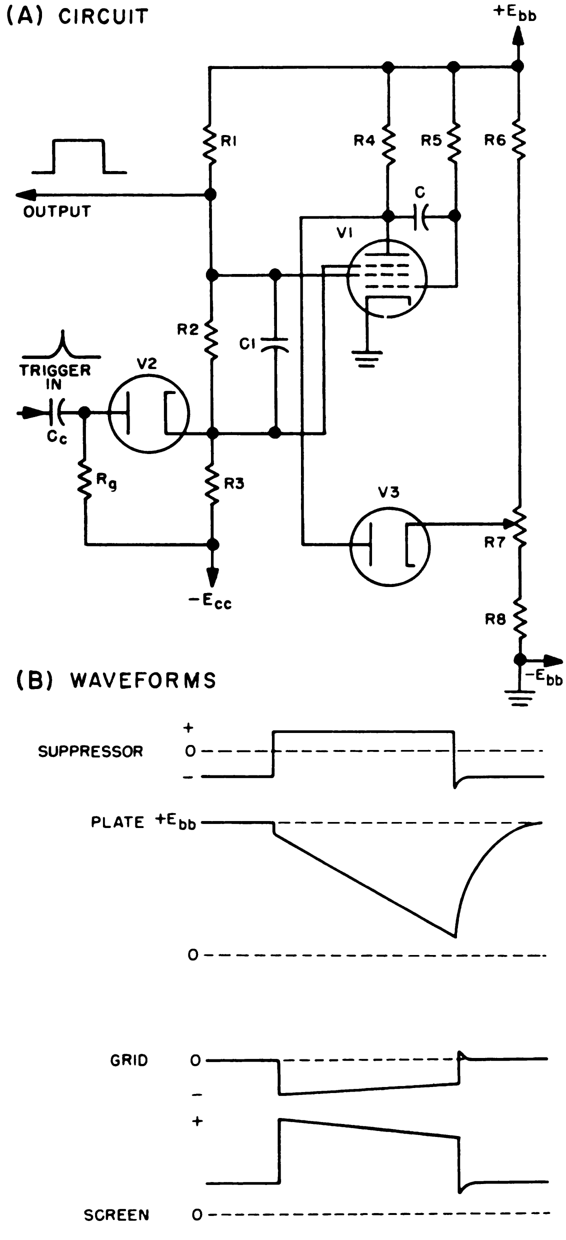

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Figure 10-8.–Basic screen-coupled phantastron.

Since the cathode is grounded and the grid is connected through R5 to B-plus, the grid remains near zero bias. Thus, although the plate current is cut off, the screen current is heavy. When a positive trigger is applied to the plate of disconnecting diode V2 through coupling capacitor Cc, the diode conducts. The positive trigger thus appears across R3 and is applied to the suppressor of V1. The trigger is large enough to overcome the fixed negative bias and drive the suppressor positive. Therefore, plate current flows through R4. (Since R4 is a relatively large value resistor, the plate current quickly goes from zero to a low value; simultaneously, the negative swing produced across R4 is applied through C to the grid, driving it from zero to a negative value. This value is only a few volts, but is sufficiently negative to reduce the total cathode current.)

The grid is now in full control, and the reduction of screen current produces a large positive increase in screen voltage. The positive-going screen voltage is fed back through C1 to the suppressor, so that the action is regenerative. As a result, the tube is quickly triggered from the static condition to the operating condition, which produces a screen waveform with a sharp leading edge. The linear sweep development or timing cycle now begins, with the plate current of V1 increasing steadily.

Since the grid is returned to B-plus, the grid voltage attempts to reach the zero bias level. It can change only slowly, however, because the plate side of feedback capacitor C is steadily decreasing. Any positive grid swing is immediately counteracted by a negative plate swing fed back to the grid. Therefore, capacitor C starts to discharge and electrons flow from the plate of V1, discharging C through R5. (Thus C discharges at a rate determined by the time constant of C and R5.) In some circuits, R5 is made variable to permit changing the rate of operation.

In discharging, the grid side of capacitor C gradually becomes more positive, causing an increased current flow through R4 and producing a constant decrease in plate voltage. The positive increment on the grid is always slightly greater than the negative plate swing it produces; therefore, the grid potential gradually rises, and the plate potential gradually drops. When the plate reaches the point where a voltage change on the grid will produce no further plate-voltage change, the turnoff point is reached.

Up to this time a positive gate has been produced in the screen circuit and coupled to the suppressor. A negative gate has been developed on the grid which is slightly smaller in amplitude from the leading edge to the trailing edge. The amount is dependent upon the gain of the tube.

The tube plate voltage is now only a volt or so above zero and the plate current can no longer increase. The grid voltage, however, is still rising toward zero, causing an increase in total current flow. Therefore, the screen current increases. The moment the screen current increases, the screen voltage drops and feeds back a negative swing through C1 to the suppressor. The suppressor grid then resumes its original negative condition, stops any flow of plate current, and assumes control again.

Since this action is regenerative, a sharp trailing edge is produced. Simultaneous with plate current cutoff, the plate voltage swings positive and feeds back to the grid a positive voltage, which helps the grid to return to normal zero bias condition. Since the charge on C cannot change instantly, the plate swing tapers off exponentially and the tube is not ready for another trigger cycle until it has completely recovered.

Diode V3, called a "plate-catching" diode (because of the way it "catches," or arrests, the positive excursion of the plate voltage), operates to catch the plate at a specific voltage. Thus, with a fixed bottoming point, the length of the output pulse (and its time duration) depend on the plate voltage fixed by V3. The cathode of V3 is biased positive by the voltage divider consisting of R6, R7, and R8, as controlled by potentiometer R7. When the plate voltage of V1 is greater than the positive voltage applied to the cathode of V3, the diode conducts and quickly bring the plate voltage of V1 down to the level of the cathode voltage.

The linear sweep action always starts at the voltage set by R7, and the duration of the phantastron gate (or the length of the sweep) is thereby determined. Because the amplitude of the plate sweep depends on the level at which it starts, R7 directly controls the amplitude. The amplitude of the screen gate is determined by the voltage applied and the screen current, and is only slightly affected by R7.

Operation occurs at a rate fixed by the discharge of C through R5. In some circuits R5 is made variable to set the maximum time delay, and R7 is provided as an external control to permit selection of the exact time duration required. Feedback capacitor C provides regenerative feedback from plate to grid, to allow quick response to any changes in the plate circuit.

CATHODE-COUPLED CIRCUIT.–A typical cathode-coupled pentode is shown in figure 10-9. This circuit is also started by a positive trigger applied to the suppressor grid and turns itself off automatically. The output can be taken from either the screen or cathode, or both. The screen output is a positive gate, and the cathode output is a negative gate.

In this circuit, tube V1 is the basic phantastron, with diode V3 operating to control the plate voltage level and determine the duration of the output gate. To minimize overshoot (positive on the control grid and cathode, negative on the screen grid), diode V2 is connected between R1 and R2 on a voltage divider network consisting of R1, R2, and R3.

The voltage on the cathode of V2 is normally 1 or 2 volts less than the cathode voltage of V1.

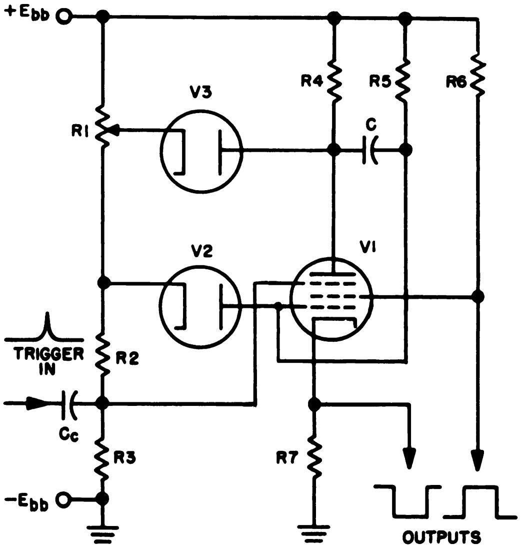

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Figure 10-9.–Basic cathode-coupled phantastron.

No negative supply is needed to bias the suppressor; cathode bias is used, and the suppressor is held at a lower positive potential than the cathode. Thus, the suppressor is effectively biased negative with respect to the cathode, cutting off plate current. The screen is drawing current, which produces a positive voltage on the cathode. When a positive input trigger appears across R3, it is applied to the suppressor. This trigger is prevented from affecting the control grid by automatically reverse-biasing diode V2.

The grid is normally biased near zero, being held by diode V2 at a potential determined by the voltage divider (R1, R2, and R3) connected between B-plus and ground, and the cathode is positive with respect to the grid by approximately 1 or 2 volts.

When the trigger is applied, it overcomes the bias between the suppressor and cathode, and plate current flows. The decrease in plate voltage, due to the flow of plate current, is fed back to the grid through capacitor C. This causes the tube current to decrease and the cathode voltage to drop. The drop in cathode voltage further decreases the bias between the suppressor and cathode, and plate current increases further. Since the total tube current is decreasing and the plate current is increasing, the screen current must decrease. This action is regenerative, and plate current will jump from zero to a value determined by the tube characteristics.

Note that the bias between the cathode and suppressor is decreasing, causing the plate current to increase. The bias between the cathode and grid is increasing. This degenerative action decreases the total tube current. Therefore, there must be a point where these two effects are equal and the current will stabilize for an instant. At this instant there is no further change in plate voltage, and the grid voltage increases in the positive direction (at a rate determined by C and R5) since it is returned to E_{bb} through resistor R5. This causes the plate current to increase.

As the plate current increases, the plate voltage decreases, and this negative change is coupled through C to the grid. This signal is degenerative, and prevents the plate current from increasing rapidly. This action continues, providing a linear sweep until the plate voltage drops to a level at which it can no longer cause an increase in plate current. At this time, degenerative feedback to the grid stops, and the grid goes in a positive direction more quickly. This causes an increase in the total tube current, and thus an increase in cathode voltage, an increase in cathode-to-suppressor bias, and a decrease in plate current.

With the total tube current increasing and the plate current decreasing, the screen current must be increasing. The action taking place is regenerative, as the plate goes positive, the grid goes positive; the plate current goes rapidly to cutoff, leaving the tube in its pretriggered condition. The positive swing in the grid is limited by the catching diode, V2. Before the circuit is ready for the next cycle of operation, capacitor C must recharge through R3, R2, V2, and R4.

RESHAPING CIRCUITS

Many different waveshapes are required in the operation of modern electronics equipment. These various waveforms are frequently generated in one form and must then be reshaped into another form for use in specific circuits. Various pulse type waveforms are sometimes deteriorated or distorted by circuit components; they must then be reshaped for use.

The basic operation of many reshaping circuits is discussed in Basic Electronics; the present discussion comprises a brief summary of the main functional applications.

LIMITERS AND CLIPPERS

The basic function of a limiter (also called a clipper) circuit is to control the extreme excursions of a waveform. The circuit accomplishes this function by removing (clipping) any portion of a waveform in excess of specified limits. Thus it limits the maximum excursion of its output waveform by clipping the extremities of the signal.

The circuit, with appropriate changes, may be used to limit the positive or the negative portion, or both. It may also incorporate amplification of the waveform, although this feature is not essential to its operation as a clipper.

Functional applications of clipping circuits include the following general classes:

1. Changing the basic shape of the waveform by eliminating the top (and/or bottom) by clipping.

2. Improving the basic shape of the waveform by eliminating the overshoots and/or undershoots on leading and trailing edges.
3. Improving the usefulness of a waveform by clipping each cycle to the same amplitude.
4. Improving the usefulness of a waveform by making each cycle have the same time duration.
5. Eliminating possible interference in the overall system by eliminating pulses of the wrong polarity.

CLAMPING CIRCUITS

Clampers, although not actually reshaping circuits, are frequently associated with limiters in functional classification. One of the disadvantages of limiters used alone is that they tend to operate around an average voltage which is established by the signal voltages. Clampers are used to overcome this fault by establishing either a positive or negative reference to which the signal voltage variations are referenced before clipping.

DIFFERENTIATORS AND PEAKERS

This class of reshaping circuits makes use of the exponential charge and discharge characteristics of RC and L/R circuits. "Differentiator" usually refers to RC circuits having a relatively short time constant with respect to the period of the input waveform. "Peakers" are usually L/R differentiators.

These circuits are normally used in pulse systems; their main application is to produce a peaked waveform or spike output. Used with square or rectangular inputs, they produce output spikes of alternate direction which are coincident with the leading and trailing edges of the input. Time duration of each pulse peak depends on the charge/discharge time constant.

INTEGRATORS

The differentiating circuit may also be used as an integrating circuit by merely changing the output tap. Differentiating circuit outputs are normally taken across the resistive component; integrators use the reactive component waveform.

RESONATORS

Some electronic equipments require oscillatory signal generation only during specified intervals. One example of this requirement is the magnetron oscillator used in pulsed radar systems. In this example, a pulse of voltage is applied to the magnetron for a short period, and then is removed for a considerably longer period. The magnetron oscillates only during that period when the pulse is applied. Effectively, a rectangular waveform of voltage has been "reshaped" into sinusoidal waveform oscillations—but only intermittently.

The same general principle is used in some range mark circuits. When the transmitter magnetron is fired, a gate circuit is also generated. This gate has a time duration approximately equal to the time required for maximum range operation. A relatively high frequency oscillator is gated by this waveform so that it produces variations to be used in the generation of range marks for timing purposes.

Another type of resonator is the ringing oscillator, where a signal is injected into a tuned circuit, which then oscillates at its resonant frequency. This type circuit is common in frequency multiplier applications, and in resonant cavities which are discussed in chapter 11 of this manual.

COUNTING CIRCUITS

A level counting circuit is one which receives uniform pulses, representing units to be counted, and produces a voltage proportional to the frequency. Either positive or negative pulses may be counted, requiring only minor changes (in the connections of the diode counting element).

With certain other modifications to the circuit, the counter may also be used, in conjunction with generating circuits, to produce a trigger pulse which is a submultiple of the PRF of the applied pulses.

All pulses applied to the counting circuit must have the same amplitude and time duration if an accurate frequency division or counting is to be made. Therefore, this circuit is usually used in conjunction with pulse shaping and limiting circuits. These circuits are used to insure standardized input pulses, with uniform amplitude and width. Pulse frequency then represents the only variable; this permits accurate measurement of the frequency variations, or division of the pulse repetition frequency.

Operation of the basic circuits is discussed in Basic Electronics. Several examples of their functional application have been presented in earlier discussion in this chapter.

OTHER CIRCUITS

Since the duration of the output waveform of the monostable multivibrator can be made almost constant, this circuit can be used as a pulse restorer. Given an input waveform of varying width, the circuit can produce output pulses having a constant duration. Many digital computer equipments make use of this circuit to restore the shape of deteriorated clock and data pulses after circulation and prior to storing.

Video mixers are frequently used to combine several individual waveforms into a single, more complex waveform. Although not a reshaping function, it should be mentioned in this section.

DEMODULATING CIRCUITS

Demodulating circuits accept composite signal inputs and separate them into their component parts. Two basic classes of demodulating circuits are considered in this discussion. The first class extracts the intelligence component from the composite input, the other class eliminates an undesirable component of the signal. The classes are distinguished by basic intent, rather than by the overall results obtained.

For example, in an amplitude modulated radio wave, the intelligence is carried in the audio component of a composite signal. In the detector circuit, this audio component is extracted from the wave. The same composite wave also contains undesired components of noise; these components are eliminated from the composite signal by filters, and by squelch and muting circuits.

Chapter 10 of Basic Electronics contains a discussion of some basic demodulating circuits. The basic circuits discussed include several types of AM detectors and several types of FM detectors. In this discussion, AM detectors are discussed under the heading "Detectors," while FM detectors are discussed under the heading "Discriminators." Noise detectors and eliminators are discussed under the heading "Squelch and Muting Circuits."

DETECTORS

All detectors incorporate nonlinear devices and signal-selective filtering. The diode is a simple device possessing nonlinear characteristics, and is the active element most commonly used in this application. The diode may be a semiconductor or a vacuum tube.

In the common diode AM audio detector circuit, the composite signal is first rectified, then the RF component is filtered out. This leaves only the audio signal component, which is then amplified and used to reproduce the transmitted intelligence. Other types of detectors perform effectively the same functions.

In the detection of AM signals, rectification is essential. The signal variations (envelope) are effectively sinusoidal in amplitude, varying about an average (reference) value. Filtering out the RF component without previous rectification would leave only the reference value, which does not vary. By the preliminary rectification process, however, one-half of the RF variations is eliminated, leaving the other half (which varies sinusoidally at an audio rate). The average (reference) value of the remaining portion of the signal does vary, so that subsequent filtering out of the RF component leaves the audio signal variations (which contain the impressed intelligence).

DISCRIMINATORS

AM detectors, as discussed previously, respond primarily to variations in the amplitude of a composite signal. FM detectors, however, respond primarily to frequency variations, although they are somewhat sensitive to amplitude variations also. Variations in the amplitude of the applied signals tend to produce distortion in the output signal, therefore most FM detectors are preceded by one or more stages of amplification and a limiting circuit.

Theory of the basic types of discriminators is presented in Basic Electronics. Three actual discriminator types in common usage are dis-

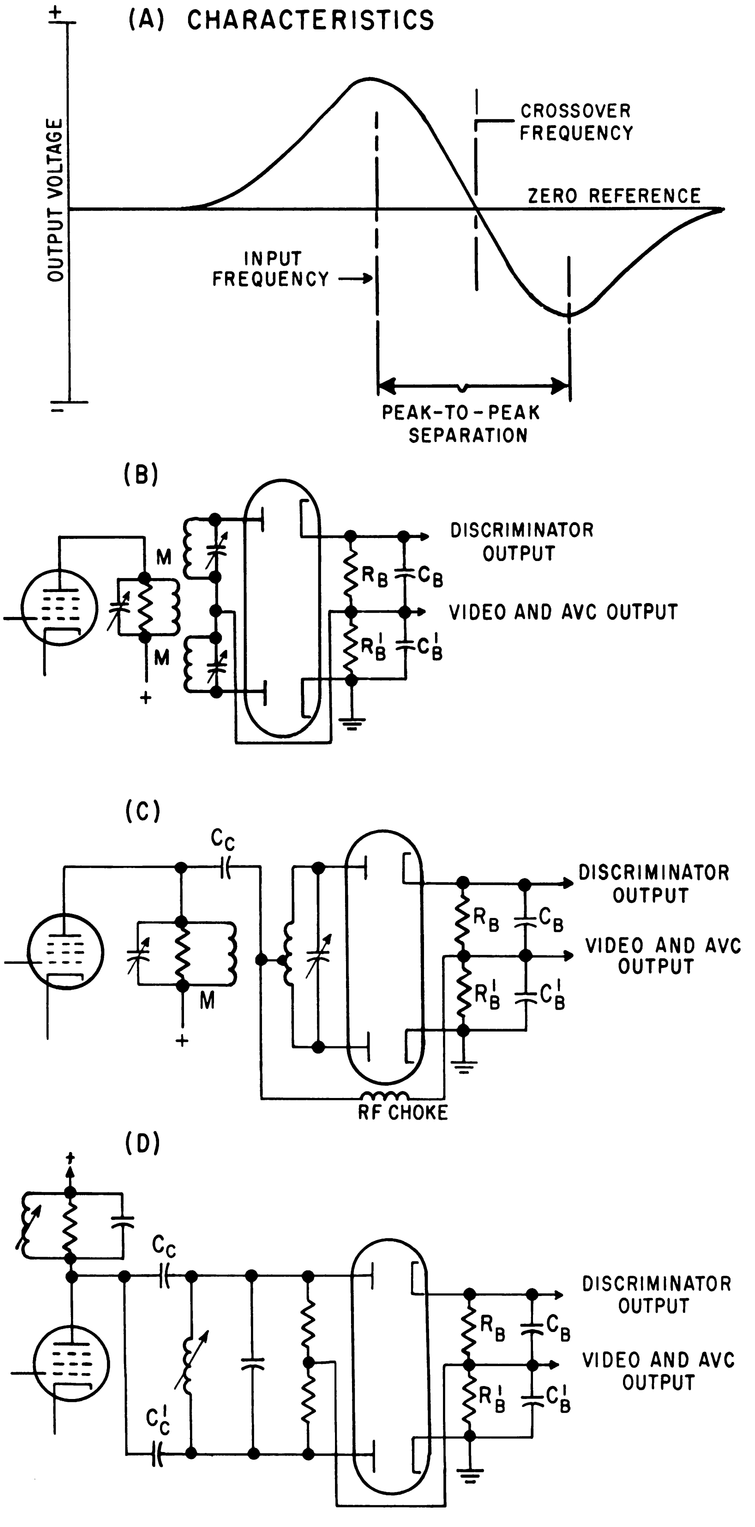

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Figure 10-10.–Discriminators.

cussed briefly in the following paragraphs. Emphasis is placed on the differences and similarities between the circuits, rather than on the operation of the individual types. Figure 10-10 (A) illustrates some of the basic terminology involved in the discussion; sections (B), (C), and (D) of the same figure show simplified circuit diagrams of the discriminators discussed.

The zero reference (fig. 10-10 (A)) may be at some d-c level other than at ground potential. The "zero" level to which polarities are referred in the discussion is the d-c voltage at the output terminals with no signal at the input terminals. The crossover frequency is the frequency lying between the two output peaks for which the output voltage is zero.

If the IF input signal consists of continuous waves, the output voltage will be d-c. If the IF input signal is in the form of a series of short pulses, the output voltage will consist of a series of pulses whose amplitude and polarity vary as indicated in figure 10-10 (A).

The TRAVIS type discriminator circuit depends upon the action of two resonant circuits. One is tuned above the desired crossover frequency and the other is tuned below. Detectors across the two circuits are connected back-to-back. The individual resonant elements are double tuned.

When close coupling is used, each side of the discriminstor characteristic may be double humped. (This is not possible in either of the other circuits.) If the peak-to-peak separation is too great for the circuit Q's in any of the circuits, the characteristic will have a "chair" shaped waveform.

Three factors may be adjustable. Crossover frequency may be shifted by tuning the two resonant elements in the same direction. Peak-to-peak separation may be adjusted by tuning the two circuits in opposite directions. A slight adjustment of the primary circuit adjusts the symmetry of the overall circuit response.

In the FOSTER-SEELEY discriminator (fig. 10-10 (C)) the mutual inductance determines the peak-to-peak separation while the crossover frequency is the resonant frequency of the secondary.

The Weiss discriminator (fig. 10-10 (D)) was developed in an attempt to reduce the detrimental effect of stray capacitances by making them serve a useful function. This is essentially the capacitance-coupled analog of the Foster-Seeley. These two discriminators have substantially identical electrical performance (gain-bandwith product).

The Weiss requires accurate control over the small difference between values of the coupling capacitors (required for a narrow band characteristic). The Foster-Seeley suffers at large bandwidths because of the large variation in mutual inductance with small displacements of the coils.

SQUELCH AND MUTING CIRCUITS

As stated previously, detector and discriminator circuits are used to extract usable components from a composite signal. Squelch and muting circuits, on the other hand, are used to extract and eliminate undesirable components from the signal. Detectors and discriminators usually accept RF or IF inputs and supply audiofrequency outputs. Squelch and muting circuits usually have noise or distorted audiofrequency inputs from which the noise and distortion are to be eliminated.

The distinction between squelch and muting circuits is quite vague. In actual practice, the same basic circuit is referred to as both squelch and muting.

Squelch circuits are usually found in ICS of in sensitive communications receivers which incorporate automatic gain control circuits. The squelch circuit is used to perform one or both of the following functions:

1. To reduce the objectionable increase in the noise output level as the receiver is tuned from one station to another.

2. To silence the receiver audio output or the ICS until a signal of usable magnitude is received.

Figure 10-11 illustrates a simplified version of a common squelch circuit.

With this type of circuit it is desirable for the receiver to come into operation with the weakest possible signal voltage. To achieve high sensitivity without excessive background noise from various sources, it is desirable to have a variable "threshold" control. This control, which is located in the cathode circuit (R8 and C3) varies the amount of bias on the squelch tube and therefore controls the sensitivity of the circuit. The squelch tube is used as a d-c amplifier to

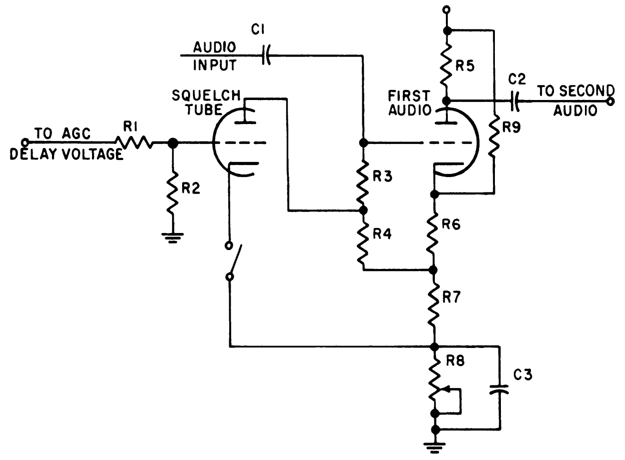

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Figure 10-11.–Typical squelch circuit, simplified.

control the amount of bias on the first audio stage.

With no input signal to the receiver, the AGC delay voltage (which is positive) appears on the grid of the squelch tube, causing the tube to draw maximum current. The current flowing through the high value plate resistor produces a voltage drop at the grid of the first audio, cutting off the stage.

For signal conditions, the grid of the squelch tube becomes negative, due to AGC action, so that this stage is cutoff and the first audio amplifier operates at normal gain.

The cathode circuit of the squelch is completed through a switch, which is normally closed. By opening the switch the squelch is made inoperative. The bias on the cathode is varied from maximum to minimum sensitivity by the threshold control R8.

COUPLING CIRCUITS

The term "coupling circuits," properly used, includes any circuit or component grouping which is used to convey the output of one functional circuit or stage to the input of another. Thus, the methods used for connecting the individual stages of amplification (discussed in Basic Electronics) are included in the general term. Also included are the various feedback methods used to produce regenerative or degenerative action in various types of circuits.

In this chapter, the discussion of coupling circuits includes tuned circuits (filters and wavetraps), transmission lines of various types and applications, delay lines (natural and artificial), and impedance matching and attenuation devices.

FILTERS AND WAVETRAPS

Chapters 3 and 4 of Basic Electronics contain a discussion of the basic theory of LCR filter circuits. The following discussion points out some important characteristics of filters and describes some other types of filters.

In electronic applications, the term "filter" refers to a frequency-selective device which operates on the basis of reactance. The usual measure of the effectiveness of a reactor device is the "quality factor (Q)." The value of Q is the ratio of the reactance to the series resistance of a coil or capacitor. The higher the value of Q, the better the filter that can be designed.

As discussed in chapter 9 of this manual, values of Q in lumped components at radio frequencies are quite limited. At progressively higher frequencies, increased use is made of the distributed properties of L and C. This permits the attainment of higher values of Q than are attainable in lumped components.

In electronic design, gain is usually cheap, but selectivity is expensive. Since filters must be frequency-selective, they are usually designed to provide the special characteristics required for their specific applications.

Characteristics of Filters

The frequency response of a circuit is a plot of the output signal strength or magnitude over a range of frequency variations, using an input of constant amplitude. Frequency response is the basis for classification of filters as low pass, high pass, band pass, and band reject. Wavetraps are usually used as band reject filters placed in the input stages of a receiver to eliminate a signal with a frequency which would cause excessive interference with reception.

Filters provide differences in output magnitudes by introducing varying amounts of attenuation at different frequencies. In addition, being reactive devices, filters introduce varying amounts of phase shift to the signal.

This phase shifting characteristic is especially important in equipments using pulse signal systems. Rapid changes in signal voltage must not generate large overshoots or undershoots. (Such conditions could damp desired oscillation, or they could cause undesirable oscillation.)

The "group delay" characteristic refers to the relative phase shift (delay) of the various frequency components of a waveform as the signal travels through the filter. A flat group delay response is usually desired because such a curve indicated that all passed frequencies are delayed by an equal amount. This reproduces the desired signal with minimum distortion. If unequal amounts of delay are desired, the filter elements must be adjusted accordingly.

Filter Types

Several types of filters other than the lumped LCR devices are used in electronic circuits and equipments. Most of these types make use of some form of resonance or near resonance as the basic operating principle.

The piezoelectric crystal resonator has a Q of several thousand. It is also relatively stable with time and environmental conditions. With such resonators, filters with high selectivity and very narrow bandwidths have been developed. The crystal, however, tends to oscillate in modes other than the fundamental frequency. The spurious modes are undesirable and unpredictable, thus limiting the usefulness of this type filter. When used, it is usually within the range of several kHz to about 20 MHz.

In single sideband applications, the mechanical filter (described in chapter 16 of this manual) is used extensively. An interesting characteristic of this type filter is its frequency response curve–sharp cutoff on one end, sloping response on the other.

Many types of filters make use of resonance in distributed properties. These include various types of transmission lines, coaxial resonators, waveguide sections, resonant cavities, etc. The July 1964 issue of the DIGEST contains an article which discusses filters in electronics.

PRESELECTOR FILTERS.–These filters are required at the input (front end) of all sensitive receivers to separate the desired signal or signals from the unwanted signals. Because the desired signal is always low in amplitude while the undesirable signals, including noise, may be appreciably greater, the preselector must have a low insertion loss to the desired signal and high attenuation to undesirable signals.

SSB FILTERS.–In contrast with the very symmetrical preselector filters, the single sideband filters for a modern communication scheme require nonsymmetrical attenuation on opposite sides of the passband; indeed, the filters in such a scheme become the heart of the system. Sometimes, instead of filters, phase difference networks are used to eliminate the unwanted sideband. In either case the purpose of thenetwork is to suppress the second sideband to such a degree that it does not contribute appreciably to the amplitude distortion and instability of the received signal.

COMB FILTERS.–The optimum filters can extract a predetermined signal from a medium where noise is prevalent or jamming is introduced. In general, the optimum filter is a device whose input consists of a signal representing the mixture of information-bearing signal and noise. At the output of this same filter, only a signal closely approximating the useful signal will be present. This is a most important application of information theory. For a signal represented by a periodic series of pulses such an "optimal" filter will be a "comb" filter which consists of a chain of narrow band filters passing spectral lines over the frequency spectrum of the signal. The comb filters pass discrete frequency components and discriminate against noise.

MULTIPLEXING FILTERS.–These filters provide multiple use of a broad frequency spectrum beam between terminal stages of a radio relaying system. It is possible to create up to one thousand telephone channels in one microwave link. In the case of a wire carrier communication network, the frequency range extends from the audio band up to 200 kHz (the same for power line communication). The use of coaxial lines widens the range of frequencies, and more communication channels can be created. The one requirement of such a filter is to obtain the sharpest possible attenuation outside of the pass band to suppress crosstalk between channels.

ANTIJAMMING FILTERS.–Artificially created noise for jamming can completely destroy the target signal if no antijamming features are incorporated in a radar system. To improve target detectability, a narrow band filter has been added. The primary requirement is that the filter operating with pulsed signals have not only selectivity but also minimize overshoots and ringing.

MATCHED FILTERS.–These, the cornerstone of a new science–correlation techniques and time domain filtering–are used for generation and detection of chirp signals, which have been widely used in radar applications for target identification. Chirp signals are prolonged pulse envelopes of frequency-modulated waves having a frequency that changes continuously in one direction without reversal. All-pass passive filters generate this type of pulse. Chirp signals can be used in communications to transmit binary data. Marks and spaces can be coded by corresponding ascending and descending frequency-modulated pulsed envelopes.

Matched filters in the above case provide a spectrum spreading technique and can make effective use of any bandwidth; tolerate large distortion; be insensitive to noise, tones, or spurious signals; resist jamming; operate with single-sideband frequency translation or Doppler shift; reject impulse noise; provide good signal-to-noise ratio; and require no synchronization. Areas of application include teletype, signaling field data, and various data entry systems.

TRANSMISSION LINES

Chapter 12 of Basic Electronics is devoted to a detailed discussion of the basic theory of transmission lines. That discussion is based on the parallel two-wire open line, and is followed by a brief discussion of other types of transmission lines and their applications. The discussion of transmission lines, as presented in this manual, reviews some of the basic considerations and discusses briefly some special types of transmission lines.

Energy supplied to the input of a transmission line moves toward the other end at a velocity somewhat less than the speed of light. At a given point along the line, the energy level varies with time in a manner corresponding to the input. Assuming a sine wave signal applied, the variations at the selected point are sinusoidal.

At any given instant of time, successive points along the line effectively have differing values of current and voltage. Moving along the line in the direction of energy propagation, the values at a given time vary sinusoidally, corresponding to the sine wave input. The length of the line required to represent a full cycle of the signal is the wavelength of that line at that frequency. Operation of a transmission line is based on the unit wavelength.

As frequency increases, wavelength decreases, becoming shorter until it eventually reaches a length which can be measured along a piece of wire. In a line representing exactly one wavelength, there are three points representing zero circuit voltage, one representing a maximum of voltage in a positive direction, and one representing a maximum negative voltage. Current maxima and zero points are also present on the line, but are displaced a quarter wavelength from the corresponding voltage points

Any ratio of voltage amplitude to current magnitude is a form of impedance. In a transmission line, the ratio of the voltage maximum to the current maximum is called the "characteristic" or "surge" impedance. It is frequently represented by Z_0.

The Z_0 of an infinitely long transmission line is the line impedance in ohms at the operating frequency seen by the source generator at the input terminals to the line. It is the result of the combination of distributed L, C, and R within the line. Within the usable range of frequencies, the Z_0 of a given line is considered to have a constant value.

Energy contained in the signal may also be considered as a form of electromagnetic wave, traveling along the line. When the "traveling" wave reaches the end of a finite length of line, its energy must be either dissipated or reflected. (Energy radiated from an antenna at the end of a transmission line is, for purposes of this analysis, considered to be attenuated.) If the termination of the line is equivalent to the Z_0 of the line, all energy is dissipated; if the load is not equal to Z_0, all or part of the energy is reflected. It travels in the form of a wave, back up the line from the load toward the source.

The "reflected" wave interacts with the "incident" (traveling) wave, producing a third wave (called the "standing" wave). This standing wave does not travel along the line, but remains stationary (hence the name). Although the instantaneous values of voltage or current at a given point vary sinusoidally, the positions at which the maxima and minima occur do not move.

The terms maximum and minimum points, as used above, do not imply that the value of voltage or current at a point remains constant. The instantaneous values vary sinusoidally, as stated. At a maximum point, however, the value at any instant is greater than that at any non-maximum point at the same instant. As in any sinusoidal variation, the polarity of the signal reverses each half-cycle.

The extremes of unmatched impedances used for terminating a line are the open circuit and the short circuit. A line with an open circuit termination displays a voltage maximum at the load end, and at each half wavelength from the end. The current at the termination is minimum, with a maximum current point occurring at the voltage minimum points. A line with the short circuit termination displays the opposite characteristics.

Lines with terminal impedance other than those mentioned above display standing waves, with intermediate voltage and current values at the end, and with the minimum and maximum points shifted to positions toward or away from the termination.

In a line terminated with an impedance greater than the characteristic impedance, the voltage maximum will appear less than a quarter-wavelength from the end. Terminated with an impedance less than Z_0, the voltage maximum will be more than a quarter wavelength from the termination. Relative locations of the voltage and current maxima and minima, with respect to each other, remains unchanged; position with respect to the termination, however, does vary with terminal impedance. The magnitude of standing waves also varies with the degree of mismatch between the characteristic and terminating impedances.

The standing waves on a transmission line are used as an indication of the efficiency of the line in energy transfer. The voltage standing wave ratio (VSWR) is the ratio of the voltage magnitudes at the maximum and minimum points. A line which is terminated in its characteristic impedance has no standing waves, as previously stated. The maximum and minimum points do not exist–the voltage is at an equal level throughout the length of the line. Therefore, the ratio of voltage is unity, or the VSWR is 1:1. This represents the maximum transfer of energy, and is called an impedance match. For maximum transfer of energy throughout the system, both the source and the load should be matched to the line. Any impedance mismatch causes standing waves, with a resultant energy loss in the line. Effectively, this constitutes an attenuation of the signal.

Although the previous discussion is based on the two-wire line, the same basic theory is equally applicable to other types. Transmission lines in common avionic usage include the coaxial cable, unshielded twin lead, shielded twin lead, dual coaxial cables, waveguides, high attenuation cables, delay lines, and low noise cables.

ATTENUATORS

Throughout the microwave region, the VSWR of a flexible transmission line may vary over a wide range. The magnitude and the frequency of occurrence of such variations increase with an increase in cable length. The changes in VSWR are due to additive or subtractive reflections. The reflections, in turn, are caused by variations of the impedance at various points along the line. Variations in the diameter or spacing of the conductors, dielectric composition or thickness, or conductivity of the individual conductors cause variations in the L, C, and R components of the sections along the line. At microwave frequencies, small variations result in relatively large reactive components of impedance, with the result that sections of the line may have Z_0 values somewhat different from that of the line. Each variation of Z_0 results in an impedance mismatch and standing waves.

Variations in the Z_0 result in variations of the VSWR. In general, the overall impedance of the line is increased, with resultant increase in signal energy losses. This constitutes increased attenuation, and is usually undesirable. Since the variations tend to increase with length of the line, the lines are usually made as short as possible at microwave frequencies.

For some applications, however, increased attenuation is desirable. Two fundamental methods are used to introduce increased attenuation: the integral and the terminal attenuators.

Integral Attenuators

Integral attenuators are used to decrease the magnitude of a signal in transit through the circuit path. The attenuator may be in the form of a high impedance cable or some other form of attenuating coupler.

High attenuation, or lossy cables, are used to provide isolations of 5 to 20 db between functional portions of a system. They reduce interaction between units which must be separately used in the same system, but whose simultaneous operation could cause undesirable interference with other circuits. This type cable is also used as dummy loads, and is capable of dissipating peak or average power values in excess of those which can be handled by most other fixed attenuators.

The easiest methods of increasing attenuation would be by changing dielectric composition or thickness, or by changing the size, spacing, or composition of the conductors. Increasing the dielectric loss is undesirable because of the variations of Z_0 with frequency changes. The most common method uses a resistive wire as the conductor. This provides increased impedance and attenuation, relatively free of changes caused by frequency variations.

In the common coaxial transmission line system, the limiting factor with respect to VSWR and operating voltage is usually the coaxial connector. The attenuation introduced by the connector is usually fairly small, but it must be considered. Total attenuation increases rapidly with an increase in the number of such devices, therefore the number of connections in a coaxial line is usually kept to a minimum.

In systems where attenuation is desired special attenuating connectors are used. These attenuators usually use a resistive wire center conductor within a circular or rectangular metal box. A conventional coaxial receptacle is normally connected at each end, and the amount of attenuation is stamped on the box. Some devices are available with tapped connections to provide a choice of attenuation. The attenuation value is stamped at each terminal.

Terminal Attenuators

Terminal attenuators are connected to the output end of the circuit. Usually called "dummy loads," their purpose is to dissipate the power developed in the equipment. Normal usage is in the tuning and testing of equipments. The dummy antenna, used in tuning transmitters, permits the loading of transmitter circuits for accurate frequency control but prevents radiation of the energy. Radiation during tuning operations creates signals detrimental to good reception at that frequency.

Use of a terminal attenuator also permits the testing of a section of a system without requiring operation of the section fed by the portion under test.

For proper operation, the terminal attenuator should present the same impedance as the unit it replaces in the system.

DELAY LINES

Artificial delay lines of the electromagnetic type are used to generate rectangular pulses of fixed duration (in radar receiver and transmitter applications); to produce a rectangular waveform from a step function of voltage (as used in starting and delay triggers for test equipment and video display units); to terminate a pulse produced by a regenerative device such as a blocking oscillator or multivibrator (as used in radar, timing circuits, and computers); and to duplicate an existing pulse at a later time (a simple case of time delay). These lines are commonly used for many types of waveshaping and pulse-forming applications.

Delay Cables

Delay cables originated as high impedance cables for better matching of high impedance circuits. High impedance is achieved by increasing the series inductance of the center conductor, which results in phase and attenuation characteristics approaching those of a low pass filter. The parameters are comparatively constant with frequency until cutoff is reached, beyond which the attenuation rises and the delay falls off rapidly.

Delays of less than a hundredth of a microsecond to 10 microseconds can be achieved with cutoff frequencies from 5 MHz to approximately 100 MHz.

These cables are used for pulse-forming networks, phase equalization and timing circuits in computers, data transmission, color television, and similar applications. (They are also very versatile in the laboratory, since their parameters can be adjusted "by the inch.")

The center conductor consists of a fine enameled wire closely spiraled around a polyethylene core. To increase the time delay per unit length, the permeability of the core can be increased by the incorporation of finely divided magnetic materials. In these types, the magnetic losses generally limit the upper frequency to about 5 MHz, which is adequate for most pulse applications.

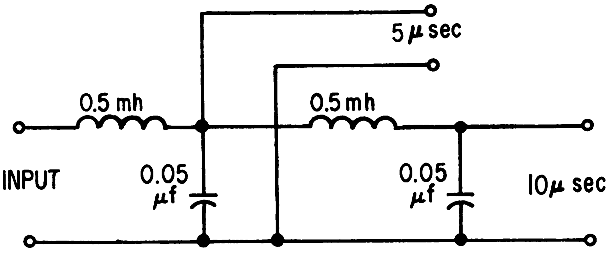
Pulse Delay Network

The delay characteristics and charging action of RF lines make them useful in some radar applications. They cannot, however, be used in others, chiefly because they would have to be too long. An actual RF line would have to be several hundred feet long for some uses in radar. Even if a line of such length were coiled up, it would occupy more space than is available Thus, so far as airborne equipment is concerned, artificial lines are used instead of actual lines.

Artificial lines possess all the electrical characteristics of actual lines, but do not have the physical bulk. They lump the required L and C values into equivalent inductors and capacitors. The result is an electrically equivalent (but physically different) line. Lumped sections of inductance and capacitance take three configurations: "L," "T,"' and "π." Of these, the "L" section is the one most commonly used. For this reason, the following explanation will be confined to this type.

In any line, a time interval is required for any voltage change to travel the length of a line. This time characteristic makes it possible to slow down the transfer of a voltage change in its travel from one circuit to another.

The artificial line shown in figure 10-12 provides a means of delaying a pulse voltage 10 microseconds. This line contains an inductance of 0.5 millihenry and a capacity of 0.05μf in each of the two sections. The time for a voltage change to move through one section may be determined from the formula $TD = \sqrt{LC}$. Total delay of the line is $TD = n\sqrt{LC}$ where n is the number of identical line sections.



AT.164

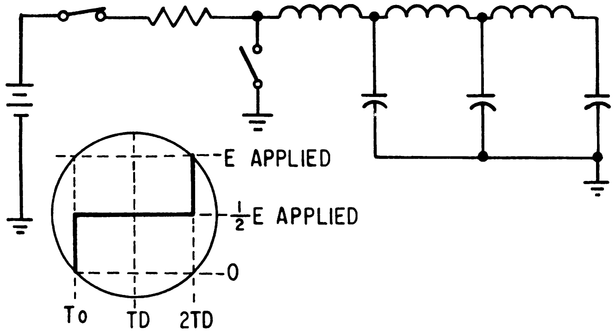
Figure 10-12.–Pulse delay network, simple circuit.

If the individual sections are not identical, time delays can be computed for each section individually, and then added together for the total delay. In most pulse delay networks in actual use, the delay times for each tapped output terminal is stamped on the unit. If necessary, inputs and outputs may be reversed; the computation of the delays between taps is based on the difference between the figures stamped at those points.

Pulse Forming Network

Another characteristic of RF lines is the manner in which the lines charge and discharge when a d-c voltage is applied to them. When d.c. is applied to an open-ended line is which the source impedance is equal to the line impedance, half the source voltage appears instantaneously across the line impedance. The change in voltage travels down the line, charging the line as it goes. When it reaches the open end, it is reflected in phase and starts back along the line. (See fig. 10-13.) All capacitors are charged to half the applied voltage during the trip down, and to full value of the applied voltage during the trip back. When all capacitors have been charged to a value equal to the applied voltage, current stops flowing. On an oscilloscope across the impedance of the source, the wave shape appears as shown in figure 10-13(B). Note that the voltage felt across the impedance of the load is half of the applied voltage during 2TD. At the end of 2TD, the PFN is charged to the full value of the applied voltage and current stops.

When the line is discharged into a resistance equal to its characteristic impedance, the result is a square wave. The wave has a con-



AT.165

Figure 10-13.—Charging a pulse forming network.

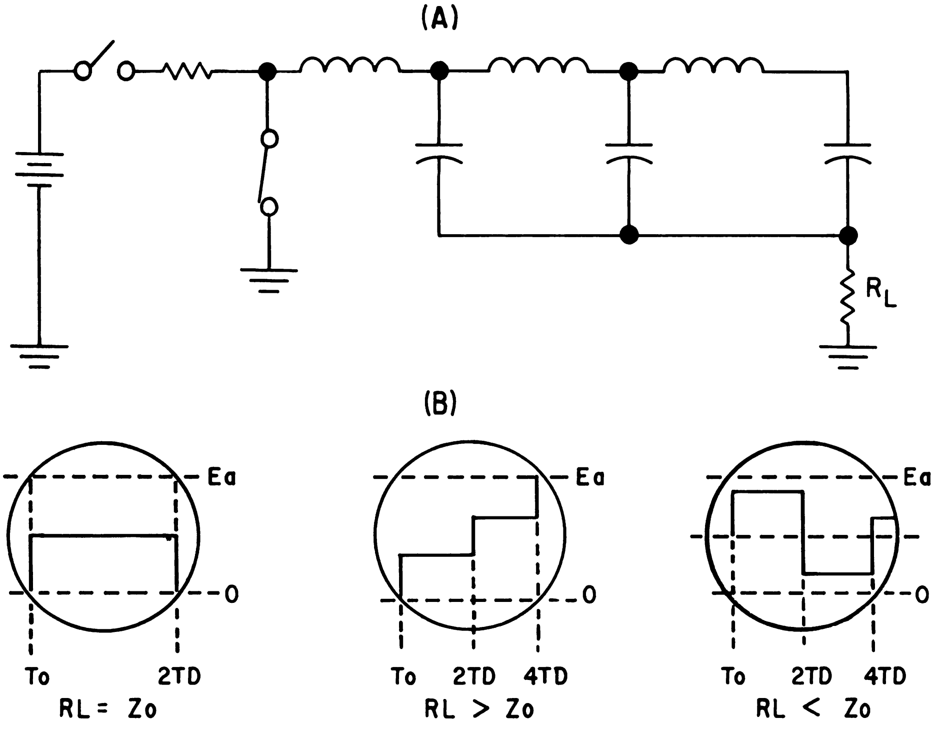
stant amplitude, and a duration equal to twice the time for the pulse to travel the length of the line. The amplitude is equal to half the charge voltage because the line discharges through its own impedance and the load impedance (R_L) in series. This cuts the load voltage by half and produces a drop of voltage which immediately travels down the line and back to the starting end, as shown in the illustration in figure 10-14.

As the end of the line is open, the reflection is in phase. This produces a voltage across the load impedance (R_L) equal to half the charge voltage and which lasts for twice the time of one-way travel on the line. Usually, an artificial line is used to generate a square wave. When the L and C are known, the time duration of the square pulse (PW) is equal to

$$PW = 2n\sqrt{LC}$$

When the termination is not equal to the characteristic impedance of the line, discharge cannot be completed in a single round trip. As indicated in figure 10-14 (B), several trips are required for complete discharge of the capacitors. The total number of trips required is dependent on the degree of mismatch between the line and its terminating impedance; the greater the mismatch, the more trips required. An artificial pulse line is capable of producing a perfectly measured square wave pulse with an amplitude of several thousand volts.

Another use of an artificial line is for forming pulses when the receiving end is shorted.



AT.166

Figure 10-14.—Discharging a pulse forming network.

The operation of the line in this case depends on energy stored in the magnetic fields around the inductors in the line. When the voltage is applied to the line as shown in figure 10-15 (A), it moves down the line and charges each capacitor. At the short circuit, the voltage turns around and returns up the line. On its return trip, it discharges all capacitors. Meanwhile, the current also moves down the line and is reflected back at the short. On its return trip up the line, its value is doubled. After one round trip, the voltage across the line at all points is zero, while the current at all inductors is high.

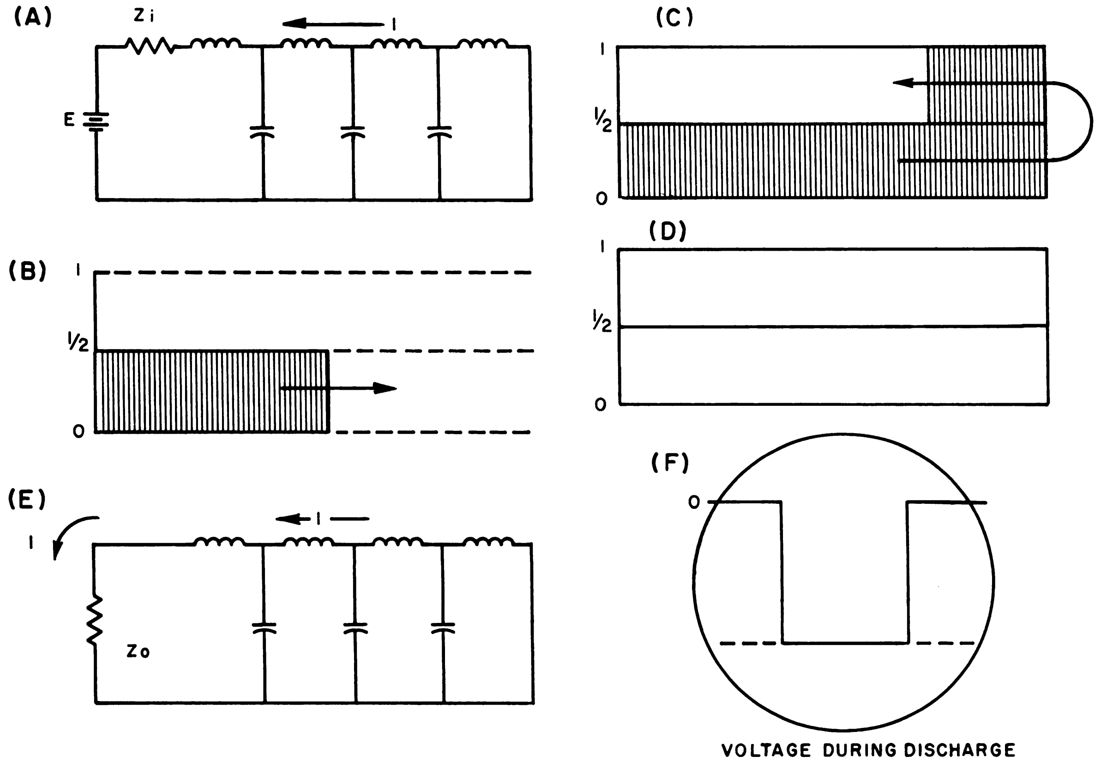
When a load is suddenly connected to the line, the current in the inductors flows through the load. This current drops to half its previous value, proceeds, to the shorted end and back, maintaining a current flow for the time of one round trip through the line.

In many radar systems, the short circuit action is produced by the firing of a thyratron tube. The resulting pulse is then used to trigger the magnetron into operation for a controlled period of time.

IMPEDANCE MATCHING DEVICES

Impedance is a complex characteristic of all a-c circuits. It consists of both resistance and reactance. Every stage, circuit, and unit within the signal path of electronic equipment or system possesses an inherent impedance with respect to the applied signal. The inherent impedance is a characteristic impedance of the functional element concerned. In addition to the inherent impedance, the input and output impedances of the element are important considerations.

The input impedance of a circuit is the impedance presented to a signal at the input to the circuit. It represents a combination of effects on the signal by the circuit and the load connected to its output. The output impedance represents the combined effects of the circuit and



AT.167

Figure 10-15.–Pulse formation, using a shorted line.

its inputs, as felt by the circuit load. These values, as shown in the discussion on transmission lines, may be equal or different.

Impedance matching is the process by which the functional circuit element is coupled to either or both the input and output circuits for optimum transfer of energy. This requires matching not only the resistive component of impedance, but the reactive component as well. For maximum transfer, the resistive components are made equal, but the reactive components are made opposite (but equal in magnitude). Thus for a capacitive reactance of one element, an equal value of inductive reactance must be found in the other.

The calculation of inherent, input, and output impedances is a complicated process beyond the scope of this course. It involves the progressive simplification of series-parallel networks of resistance and reactance components with reflected and distributed properties. Many of the individual values cannot be measured directly. These values must be calculated under varying conditions of frequency and load, including the effects of tube and transistor operation.

Fortunately, however, the technical manuals for many electronic systems and test equipments contain data concerning the input and output impedances recommended for proper matching. Numerous devices are available which have the proper impedances for use in connecting test equipment to units under test. Many technical manuals also contain the specifications and construction details for making impedance matching devices for common applications.

For most common needs, coaxial adapters are supplied as part of newer test sets. This greatly simplifies the impedance matching procedures. As a means of checking the impedance match between physical units, especially at microwave and UHF frequencies, a special class of test equipment, the "slotted line" is provided. This device is used to measure standing waves of voltage on the line, and is usually adjusted for unity standing wave ratio.

CATHODE-RAY CIRCUITS

The circuits used for the electrostatic type of cathode-ray are functionally similar to those used for the electromagnetic type of tube, but differ in the manner of accomplishing their function. Basically, the cathode-ray tube provides a fast moving, easily and quickly deflected electron beam for use in waveform viewing and analysis, and for special display purposes. Generally speaking, the display types of CRT are magnetically controlled, while the types used in test oscilloscopes and synchroscopes (for waveform checking) are electrostatically controlled.

All cathode-ray tubes have basic control circuits which are necessary if the tube is to be used at all. These circuits control intensity (brilliance), focus, and beam positioning (centering, both horizontal and vertical). Other circuits with which the CRT is concerned are horizontal and vertical amplifiers, sweep circuits, and synchronizing circuits. All of the latter are standard circuits, with special attention paid to the design for bandwidth, response, and linearity. In some special cases there are peculiar circuits which are mainly combinations of standard circuits used for packaging the component into a convenient size, and for economy. For example, while a console unit may have high and low voltage supplies, they are usually separate and use separate transformers, whereas the conventional oscilloscope uses one transformer to supply both high and low voltage, bias, and filament power.

FOCUSING METHODS

Three basic focusing systems are used in CRT's, but all three accomplish the same function: they focus the electron beam so that it forms a sharp spot as it impinges on the face of the CRT. The three systems are the permanent magnet, the electrostatic, and the electromagnetic.

The permanent magnet and the electromagnetic systems are identical in effect; they differ only in the manner of producing the magnetic field. A form of electromagnetic focusing is discussed (in connection with klystrons) in chapter 11 of this manual. Although that method is considerably more complex than is normally the case in CRT circuits, the basic action is similar.

The permanent magnet focusing method is usually found in commercial television receivers; it is not in common usage in avionic equipments. Electrostatic focusing is found in small-screen CRT's used in test oscilloscopes and in the auxiliary indicators of some radar sets.

ELECTROSTATIC DEFLECTION

The following circuits were chosen as basic examples of the circuits generally used in electrostatic CRT's and oscilloscopes. Each was selected to bring out the basic principles and requirements necessary for circuits used in waveform analysis. The discussion is limited to the essentials needed for describing their use with cathode-ray tubes.

Beam-Positioning Circuits

A simple oscilloscope using basic beam-positioning circuits is shown in figure 10-16.

Note that the voltages are taken from a common voltage divider between B-plus and B-minus. The divider is grounded at a convenient point, usually at the positive voltage required for the accelerating anode (A2), and both ends are above ground. With the positive low voltage and negative high voltage at above ground potential, the case and chassis can be grounded for protection of the operator. This system also permits the anode and one of each pair of deflection plates to be grounded, to form a simple unbalanced deflection or positioning circuit. This connection also keeps the deflection plates and accelerating anode at the same potential and avoids defocusing effects from differences in potential between them.

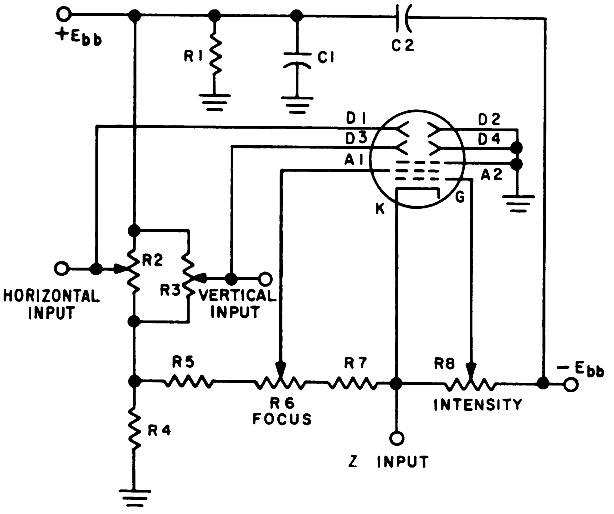


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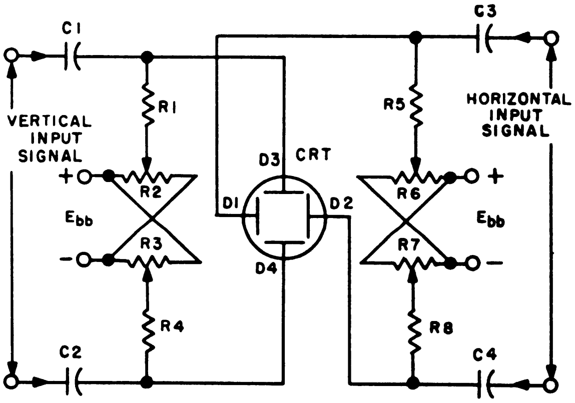
Figure 10-16.–Simplified schematic of basic oscilloscope.

In the balanced positioning circuits (fig. 10-17), each deflecting plate (D1 through D4) is controlled by a separate potentiometer, and the plates are isolated and balanced equally by being connected to the position controls through equal resistors. Each plate is also connected to the deflection amplifiers, through a coupling capacitor, in a push-pull arrangement. Thus the CRT is balanced for d.c., for a.c, and for any stray capacitance to ground. Since the isolating resistors (R1, R4, R5, and R8) are always of a very large value, the deflecting plates may be connected into any circuit without danger to the operator. (It takes a current of only a few microamperes to drop the positioning voltage to zero).

Sweep Circuit

To provide a time base for the waveform, the CRT beam must be deflected horizontally across the face of the tube from left to right, then caused to return quickly from right to left, ready to resume another cycle of operation.

Some oscilloscopes provide blanking for the retrace period so that the return sweep cannot be seen. A typical thyratron type sweep generator for general oscilloscope use is illustrated and explained in Basic Electronics.



AT.169

Figure 10-17.–Balanced positioning circuit.

Other types of relaxation oscillators, such as a neon tube, a vacuum tube RC oscillator with discharge tube, or a multivibrator, could be used, provided that a reasonably linear sawtooth sweep waveform is produced.

Synchronizing Methods

To keep the waveform stationary on the face of the CRT, the sweep frequency must be an exact multiple or submultiple of the waveform under observation. To avoid the need for constant resetting of the sweep frequency control (because of drift, power supply voltage changes, etc.) a sweep-locking or synchronizing circuit is provided.

Since some circuits do not have an output of the proper polarity for synchronization, an adjustable synchronizing circuit is sometimes included to permit selection of sync signal and choice of sync polarity. Figure 10-18 shows a typical sync input circuit of this type. Switch S1 selects one of three inputs: an external synchronizing signal, a 60-hertz signal (usually taken from a filament winding), or the output from the vertical amplifier (this is the signal under observation, but it is called internal sync). It then applies the input through coupling capacitor C1 to the grid of V1.

Tube V1 is a paraphase amplifier, with the grid returned to ground through R1. The tube is cathode-biased and unbypassed; the plate and cathode resistors (R2 and R3) are of the same value, so that for the same current identical signals are developed in the plate and cathode circuits (except of opposite polarity). For a positive input signal, a negative plate output signal is developed, and the cathode output signal is positive. For a negative input signal, a positive plate output signal is developed, and the cathode is negative. Both plate and cathode outputs are coupled (through capacitors C2 and C3) to a common variable load resistor, grounded at a center tap. At the ground position, both signals are of zero amplitude; therefore, no output is obtained.

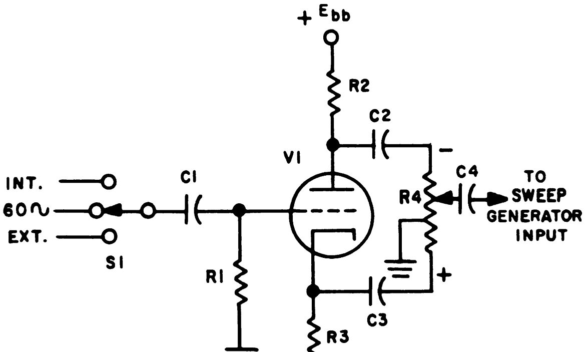


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Figure 10-18.–Typical sync input circuit.

As R4 is rotated in either direction, the signal amplitude is increased. Since the synchronizing signal to the sweep generator must be of positive polarity, for a negative input to V1 a positive signal is available on the plate side, and for a positive input to V1 a positive signal is available on the cathode side. Thus a signal similar to the input signal but of positive polarity is obtained and coupled through C4 to the sweep generator.

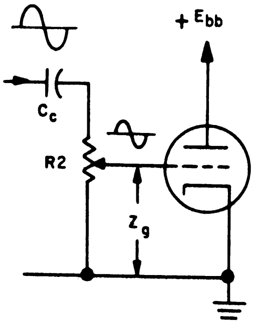
When the sweep generator is adjusted to a slightly lower frequency than that desired, a positive-going sync signal is applied to the grid, the sweep generator locks in and operates at the same frequency as the sync signal. Thus the CRT waveform remains stationary, rather than drifting across the screen, because it is synchronized so that the sweep occurs at the same place (at the same time) each sweep.

To produce satisfactory deflection with small signals, it is necessary to employ both vertical and horizontal deflection amplifiers. These stages may be single-ended or push-pull (unbalanced or balanced); they are conventional video amplifiers designed for the desired frequency response and linearity. The horizontal amplifier in a good scope is identical to the vertical amplifier, permitting the same signal to be applied to the X (horizontal) axis or to the Y (vertical) axis.

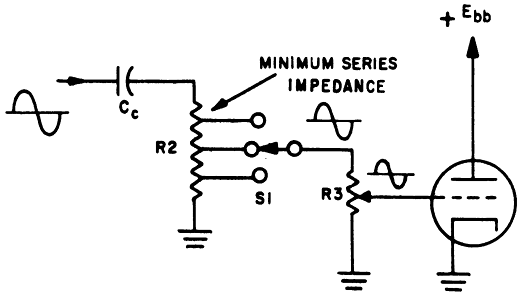
Attenuators

Since the vertical amplifier must be able to amplify very weak signals with sharply rising waveforms, it must have good frequency response and large amplification. To cover the range of signal amplitudes encountered, the vertical input is usually provided with an attenuator. Three types of attenuators are shown in figure 10-19.

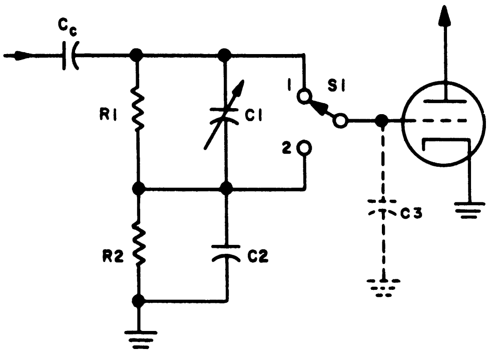
The simple circuit shown in (A) uses a potentiometer as the output load resistor of an RC coupling network. The grid-to-ground impedance of the input tube is in shunt across the lower portion of the potentiometer and in series with the upper portion. As the potentiometer arm is moved upward, the impedance presented to the circuit under test is decreased. This results in less attenuation of the signal and less loading of the circuit.



(A) POTENTIOMETER



(B) STEP POTENTIOMETER



(C) FREQUENCY COMPENSATED STEP

AT.171

Figure 10-19.–Attenuators.

The simple step attenuator circuit shown in (B) is a better type of input circuit, allowing coarse selection of the attenuation ratio with switch S1, and fine adjustment with potentiometer R3. Even for the smallest input step resistance, the full range of R3 is available for control. With the available settings of S1, the input impendance will never decrease to a value less than the series section of R2 (that portion above the upper tap) plus the parallel combination of the remainder of R2, R3, and the grid-to-ground impedance of the input tube.

The most desirable input impedance is in the range of megohms, with little or no shunting capacitance to ground. To achieve this result, a cathode follower input stage is sometimes combined with a step attenuator to isolate the oscilloscope input from the stage being tested.

Frequency compensated attenuators are used in the better type of oscilloscopes to minimize the effect of input capitance (fig.10-19 (C)) by presenting identical impedance response curves to the circuit under test for the various attenuator settings.

Frequency compensated attenuators provide the same voltage division ratio to resistive and reactive components of the input signal, so that the drop in signal level at the higher frequencies can be compensated in the video amplifiers. Attenuator compensation is usually effective over the entire useful frequency range of the oscilloscope.

Most attenuators and amplifiers have reduced high frequency response because of the shunting effect of stray capacitance. A parallel RC circuit is usually inserted in series with the input lead to boost the relative response of the attenuator at high frequencies. Another device is an input probe located at the end of a special connecting cable which applies the input to the vertical amplifier. The probe houses a frequency compensated voltage divider, to reduce the amount of shunt capacitance at its input terminals. This is usually called a DC probe (or simply input probe), as distinguished from an

RF probe which contains a diode rectifier to remove the modulation.

Signal Amplifier

A typical three stage signal amplifier is shown schematically in figure 10-20; it drives a conventional push-pull paraphase deflection output amplifier. The input signal is applied through blocking and coupling capacitor C1 to a cathode follower attenuator stage incorporating triode V1. The attenuator is a two step, frequency compensated type.

Y-gain (vertical) control R6 controls the amplitude of the input signal to the video amplifier consisting of V2 and V3. Both high frequency and low frequency compensation are employed in each stage. The cathode of V2 is bypassed by a small capacitor, which makes it degenerative for low frequencies, thus reducing the response and flattening out the low frequency response. The high frequency response is increased by peaking coils L1 and L2 (which compensate for the shunting effect of tube and wiring capacitance and provide a reactance which increases with frequency).

Amplifier V3 is fixed-biased by connecting the cathode to the junction of R13 and R14, which are connected in series between the plate supply and ground. Cathode resistor R14 is also unbypassed so that the circuit is completely degenerative for high and low frequencies, further improving the overall frequency response. The use of the fixed cathode bias sets the operating point of V3 and helps stabilize the stage.

An output from the cathode of V3 is taken for application to the sync circuit for internal synchronization. The main output of V3 is fed to cathode follower output stage V4, which is biased positive with respect to ground by plate current, even though the cathode is returned to the minus supply. Variable potentiometer R16 serves as output control to adjust the signal amplitude for application to a paraphase amplifier.

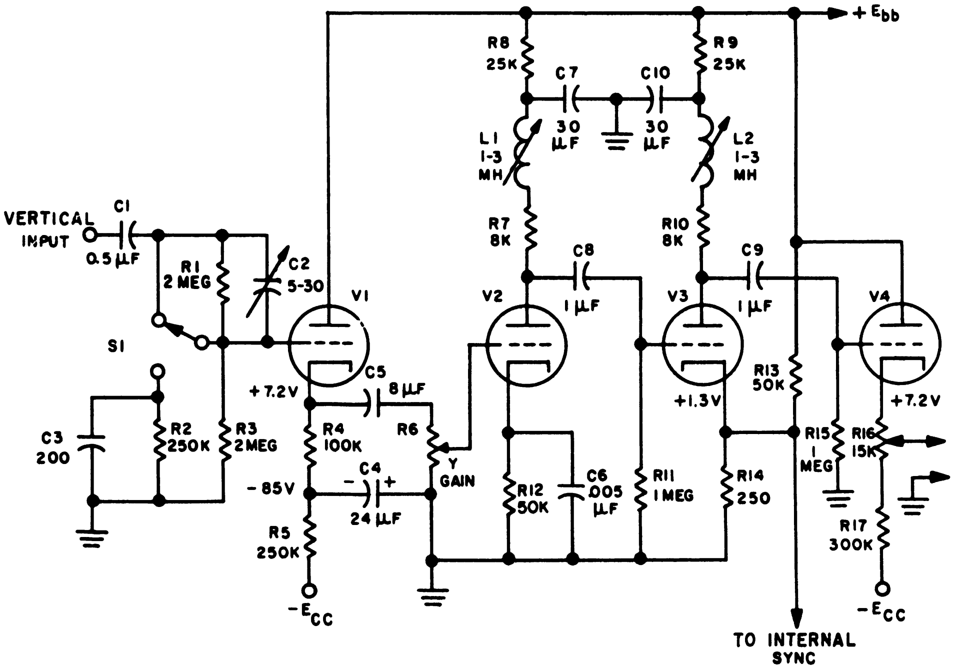


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Figure 10-20.–Three-stage signal amplifier.

Deflection Amplifier

A common type of deflection amplifier used for electrostatic deflection is the paraphase amplifier, shown in figure 10-21. In this type of circuit, a balanced output is obtained from a single ended input signal by means of common coupling in the cathode circuit of both tubes. (The circuit is known as a cathode-coupled paraphase amplifier.)

The input signal, shown as a positive pulse, is applied to the grid of V1, with the grid returned to ground through R1. Cathode bias is obtained by means of R2, which is common to both V1 and V2. Since R2 is unbypassed, the input signal at the grid of V1 also appears at the cathode, while the inverted signal appears at the plate as one output of the circuit. The signal at the cathode of V1 is applied, through direct connection to the cathode of V2.

The grid of V2 is connected to a balance potentiometer which acts as a voltage divider between E_{bb} and ground. Thus the output signal of V2 can be adjusted to equal that of V1. The positive pulse at the cathode of V2 increases the bias, decreases the plate current, and produces a positive output at the plate of V2. The plate output signal of V2 is reversed in polarity from the input signal, as in any ordinary vacuum tube amplifier.

The input to V2 is the signal voltage developed across R2. This signal is applied to the cathode of V2 (which has its grid returned to ground through R5 and is thereby at ground potential to the signal). Therefore, the output signal at the plate of V2 has the same polarity as the input signal at the cathode of V2 or the input signal at the grid of V1. In this way, the output signals from the plates of V1 and V2, which are applied to the deflection plates of the CRT, are equal in amplitude but opposite in polarity (phase).

The circuit operation and the schematics given above have, for simplicity, omitted the additional compensation networks which are often included in specific applications. In order that deflection amplifiers do not restrict the bandwidth of the input signal, they must have wide frequency response, low distortion, and time delay proportional to frequency, similar to the characteristics of video amplifiers.

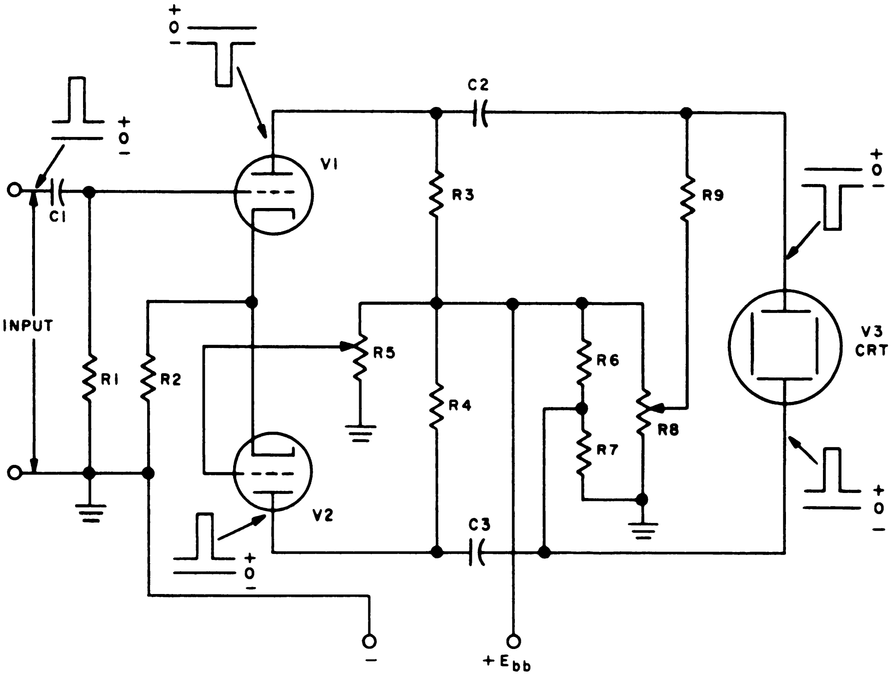

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Figure 10-21.–Paraphase voltage deflection amplifier.

ELECTROMAGNETIC DEFLECTION

When a very large screen is used and correspondingly large deflections are required, it is not practical to use electrostatic deflection. The extent of deflection desired would require greater spacing between the deflection plates and, consequently, unusually high signal voltages would be necessary. It is simpler to obtain large deflections in a relatively short tube by means of magnetic fields. In addition, with magnetic deflection, it is easier to obtain the special types of sweep required by radar PPI, scanning sonar, and television picture tubes.

It should be noted that both the electrostatic and electromagnetic deflection systems have their advantages and disadvantages. The electrostatic deflection systems are used when high sweep frequencies are needed. The electromagnetic systems have the disadvantages of frequency limitations and high weight and large size.

The common method of obtaining electromagnetic deflection is to use two pairs of electromagnets around the neck of the CRT. This simplifies the construction of the tube since no internal deflection plates are required and focusing is also accomplished electromagnetically. Instead of applying a signal voltage across deflection plates, the final signal amplifier tubes send a strong signal current through the electromagnets. The amount of current varies to follow the signal that is being examined, and thus the electron beam deflection is proportional to the signal.

Trapezoidal Input

Figure 10-22 illustrates a simplified typical deflection amplifier for producing a horizontal time base using magnetic deflection. The input signal is a trapezoidal waveform of voltage as shown in the illustration.

The input is applied through coupling capacitor C1 to the grid of V1, which is operated as a Class A stage with fixed bias. Sufficient negative bias is applied to prevent the grid from going positive with maximum signal input. V1 is a pentode or a beam power type, in order to obtain the power amplification required to furnish current to the deflection coil (This coil may require between 50 and 100 milliamperes of current for maximum beam deflection.)

The output of V1 is applied to the deflection coil, which in the illustration is represented by an inductance, L1, with a resistance, R2, in series with it. R2 is shown as a dotted resistance because it is actually a part of L1. The output voltage waveform at the plate of V1 is trapezoidal; when this waveform is applied to the series R-L circuit (deflection coil), the voltage waveform appearing across the resistance is resolved to a sawtooth shape, while that appearing across the inductance is resolved to a square-wave shape.

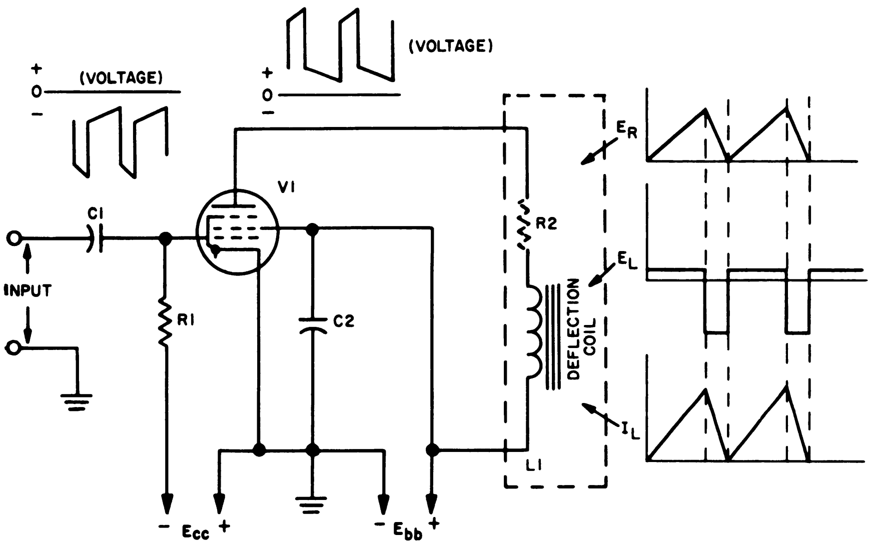
The square wave of voltage across the inductance causes a sawtooth wave of current through it, which is the required waveform for producing a horizontal time base deflection on the screen of the cathode-ray tube. The development of the sawtooth current waveform from the trapezoidal voltage input waveform is shown in figure 10-23.

The trapezoidal voltage input waveform to the grid of amplifier V1 is shown in (A); the differentiated voltage which appears across the inductance is shown at (B); the integrated voltage which appears across the resistance (of the coil) is shown at (C); the current through the deflection coil, which is the composite result of waveforms (B) plus (C) is shown at (D).

Square Wave Input

The input signal to the amplifier (shown in fig. 10-24 (A) is a square wave, instead of the trapezoidal wave required in the previous circuit. This signal is applied to the grid of V1. The grid is returned to ground through resistor R1. The positive voltage applied to the cathode of V1 (from the plate supply by means of the voltage divider action of R3 and R2) maintains V1 biased to cutoff in the absence of an input signal.

When the first positive pulse of the input square wave reaches the grid, the tube conducts heavily. The resulting plate current, flowing through deflection coil L2 and inductor L1, rises exponetially toward a value which would be limited only by the resistance of the circuit. Before this limiting point is reached, however, conduction of the tube is suddenly interrupted by the negative going end of the square wave input pulse. In this way, only a relatively linear portion of the exponentially rising waveform is utilized.



AT.174

Figure 10-22.–Electromagnetic deflection amplifier.

When the conduction of the tube is interrupted at the end of the positive square wave, V1 is cut off, and the current decays rapidly to zero. This rapid decay is due to a change in the time constant of the circuit between the rise and fall of the current.

During the rise of current, the circuit time constant (L/R) is long. The resistance is composed of cathode resistor R2 and the low value of plate resistance of V1. During the decay of current, the time constant is made short, as a result of the increase in the value of plate resistance when V1 stops conducting. With the shortened time constant, the current decays rapidly.

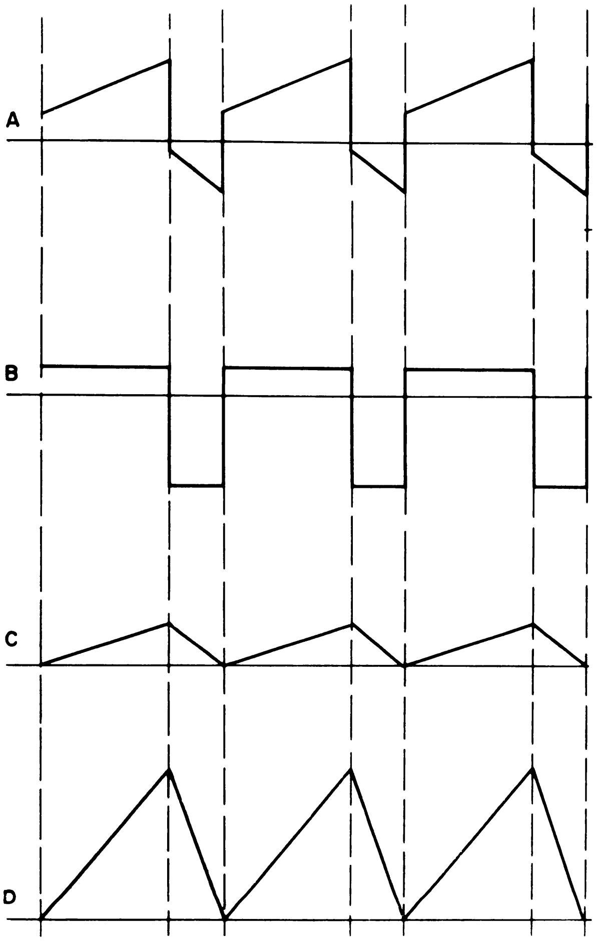
The sudden decay in current flowing in the deflection coils when the tube stops conducting causes a counter emf in the coil, which opposes the current decay. In addition, the circuit may be shock excited into oscillation by the sudden change in value of current. Although the oscillations gradually die out, they may continue into the following sweep, especially if the circuit Q is high. This condition may result in a nonlinear start of the buildup of current in the coil, and therefore a nonlinear sweep, as shown in figure 10-24 (B).

These oscillations can be eliminated, or damped out, by lowering the Q of the circuit by means of a resistor shunted across the coil. This wastes some of the deflection current, however. A more satisfactory method incorporates the use of a damping diode shunted across the deflection coil, as shown in figure 10-24 (C), where diode V2 acts to damp out the oscillation.

The current through V1 is increasing during the rise of the sawtooth current wave shown in (B), to provide the sweep deflection. The voltage at the plate of V1 is lower than the plate supply voltage by the amount of voltage drop in the deflection coil and inductor. The cathode of damping diode V2 is therefore more positive than its plate, and the diode will not conduct.

When the current through V1 falls to zero at the end of the sawtooth current wave, the voltage at the plate tends to rise above the plate supply voltage due to the fact that the cemf (generated by the inductance) adds to the plate supply voltage. When this condition is reached, damping diode V2 conducts, and any oscillations are dissipated in resistor R5.

Balanced output (push-pull) circuits, when used, usually operate by means of a phase inverter circuit fed from a single ended source. In some radar deflection circuitry, the two outputs obtained by means of a phase inverter are separately amplified by individual single ended deflection amplifiers, and then applied to the two separate windings of a split winding deflection yoke.



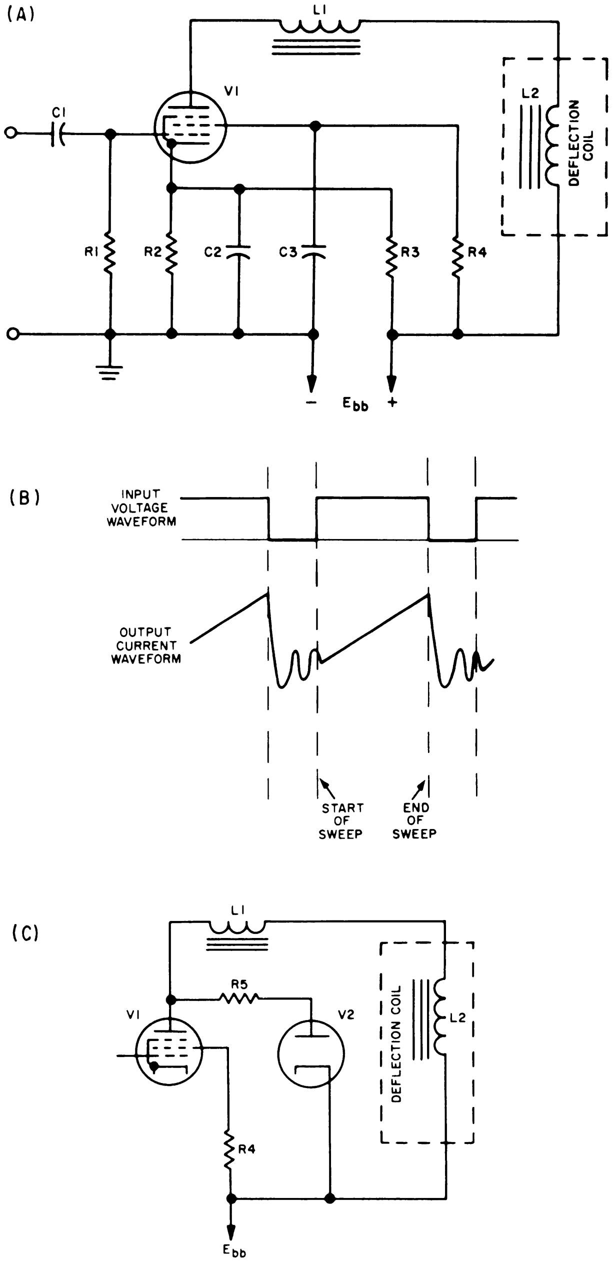
AT.175
Figure 10-23.–Development of sawtooth current waveform.

CONTROL CIRCUITS

This discussion will cover some of the commonly used circuits which control the voltage gain of an amplifier stage or control the frequency of a local oscillator stage.

AGC AND AVC SYSTEMS

In common electronics usage, the terms "automatic gain control" (AGC) and "automatic volume control" (AVC) are used almost interchangeably. Technically, however, AVC is properly applied only to circuits whose ultimate output is an audible signal. AGC is a broader term which includes audible signals and inaudible signals of all varieties. The circuit itself provides a means of automatically controlling the output of an amplifier, by regulating the gain in accordance with the strength of the input signal. Since the same basic circuit is used for both the audible and the inaudible signal, this discussion will use the term AGC in all applications.



AT.176
Figure 10-24.–Deflection amplifier, square wave input.

In most circuits controlled by AGC voltages, remote cutoff amplifiers are used. Before proceeding with the discussion of AGC systems, a brief review of the characteristics of a remote cutoff pentode is presented.

Remote Cutoff Pentode

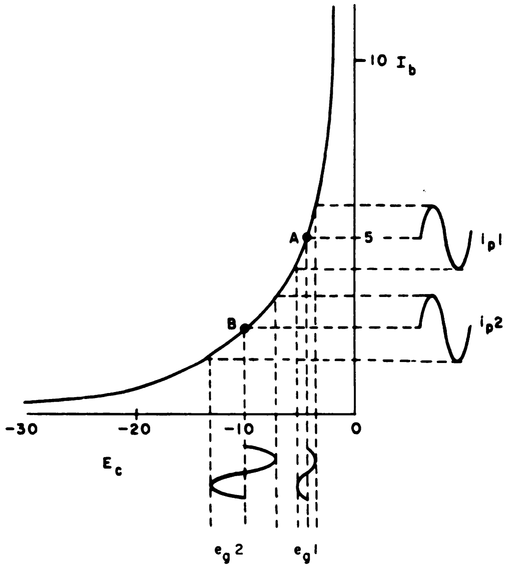
Figure 10-25 shows the E_c/I_b characteristic curve for a typical remote cutoff pentode used as an RF or IF amplifier, and the effect on plate current variations caused by changes in control grid bias.

When the signal input to the tube is small (e_g1), the developed voltage is low and the plate current variation (i_p1) is centered about point A. When the signal input to the receiver is large (e_g2), the developed voltage increases and the plate current variation (i_p2) is centered about point B. The plate current variation resulting from a small input and the plate current variation resulting from a large signal input are approximately equal, in theory; this should produce output signals of approximately the same amplitude.

Although the relationships given in the illustration are idealized, they serve to show the effect of applying a negative control voltage to an amplifier stage. In actual practice, it is necessary to supply the AGC voltage to several

effect of applying a negative control voltage to an amplifier stage. In actual practice, it is necessary to supply the AGC voltage to several

remote cutoff amplifier stages simultaneously in order that the cumulative effect will produce a satisfactory control of signal amplification by the controlled stages.



AT.177

Figure 10-25.–Remote cutoff pentode E_c/I_b curve.

Circuits vary somewhat because of the overall gain characteristics required of the receiving system. However, most AGC circuits fall into one of three general classifications: simple AGC, delayed AGC, and amplified and delayed AGC. These three classifications of AGC circuits are described briefly in the paragraphs which follow.

Simple AGC

A simple AGC circuit and a diode detector circuit are very similar in many respects. For this reason, the AGC circuit and the signal detector circuit of a receiving system are frequently combined within a single stage. Figure 10-26 illustrates a simple AGC system. This system makes use of a negative d-c control voltage obtained directly from the signal detector output, since the rectified voltage produced by the detector is proportional to the amplitude of the received carrier.

The RF amplifier, mixer, and first IF amplifier stages are series fed and controlled by AGC voltage taken from the detector diode. (The second IF amplifier stage is self-biased and is not controlled by AGC voltage.) R1 is the detector load resistor and capacitor C1 is the RF bypass capacitor for R1. Resistor R2 and capacitor C2 form an RC network to filter the AGC voltage obtained from the detector. Resistor R3 and capacitor C3 form a decoupling network for the mixer stage; similarly, resistor R4 and capacitor C4 form a decoupling network for the RF amplifier stage.

The time constant of the RC filter is long enough to remove the lowest modulation frequencies from the d-c voltage, but short enough that the d-c bias level changes in response to moderately rapid changes in received signal strength (due to signal fluctuations, fading, etc.). The simple AGC circuit is employed in many typical AM superheterodyne receivers which use a diode type detector; it is also employed in some FM receivers which use a ratio-type detector.

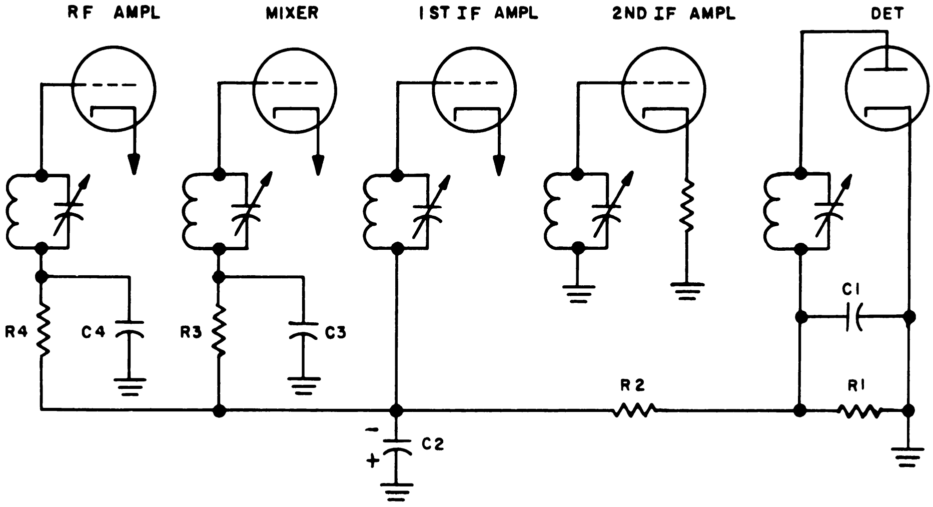


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Figure 10-26.–Simple AGC system.

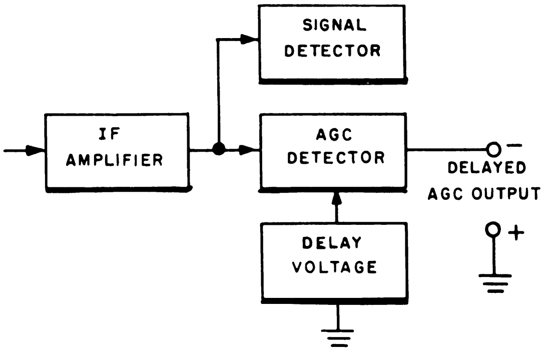
Delayed AGC

The term delayed AGC is used to denote a voltage delay, and should not be confused with a time delay. The simple AGC system just described is effective on all received signals, from the weakest to the strongest. It has the disadvantage of developing an AGC voltage even for very weak received signals. As a result, the sensitivity of the receiver to weak signals is reduced considerably. In order to increase sensitivity and enable the receiver to respond to weak signals, it is desirable to provide a means of delaying the application of AGC voltage until the received signal reaches a predetermined value, sometimes called the threshold level of AGC. Figure 10-27 illustrates a typical delayed AGC system.

The delayed AGC system makes use of a fixed delay voltage applied to a separate AGC detector. The delayed AGC detector must be a separate diode, independent of the signal detector (demodulator) because the fixed delay voltage prevents the AGC detector diode from rectifying an RF signal until the signal level exceeds the value of the delay voltage. (If separate diodes were not used, the delay voltage would prevent the detector diode from rectifying weak signals below the threshold level established by the value of the delay voltage.) Once the signal level exceeds the value of the delay voltage, the AGC detector begins to rectify the signal, and produces a d-c output voltage which is then applied as bias to the controlled stages. Filtering of the d-c output voltage removes amplitude modulation components; the RC time constant considerations are essentially the same as for the simple AGC system. The delayed AGC circuit is employed in many AM superheterodyne receivers, as well as in microwave and radar receiving systems.

Amplified and Delayed AGC

There are many variations in amplified and delayed AGC systems. However, these can be classified according to two categories: systems



AT.179

Figure 10-27.–Delayed AGC system.

which amplify a signal before rectification to obtain the AGC voltage, and systems which amplify the AGC voltage after signal rectification. In either case, a form of delayed voltage is incorporated so that the maximum sensitivity of the receiver can be realized for weak signal reception. When amplified and delayed AGC is used to control a receiving system, the overall output versus signal input characteristics can be made to approach an almost ideal condition.

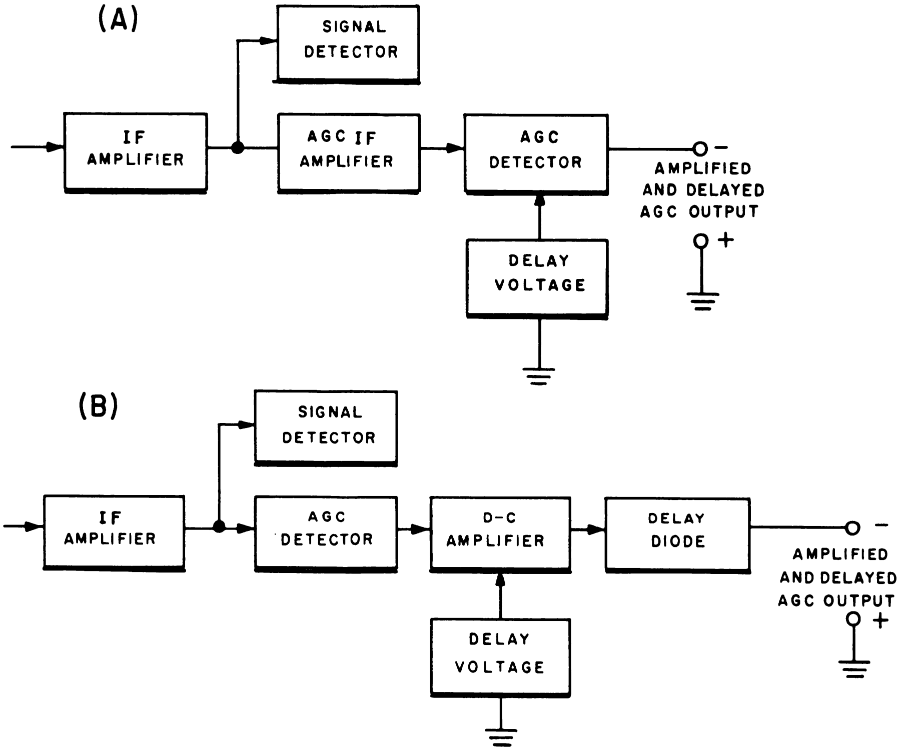
Figure 10-28 shows block diagrams for two basic types of amplified and delayed AGC systems. Section (A) of the figure shows a system in which the signal is amplified by an AGC IF amplifier before rectification by the AGC diode. Section (B) shows a system in which the signal voltage is amplified by a d-c amplifier after rectification by the AGC diode. The d-c amplifier stage is followed by a delay diode. AGC voltage is supplied to the controlled stages only when the diode's cathode is negative with respect to its plate, and the diode conducts. When the delay diode is not conducting, the AGC output voltage is zero and the receiver gain is at maximum for signals below the threshold of AGC operation.

The delay voltage is applied to the AGC detector, which follows a separate amplifier. The AGC IF amplifier receives its signal from the last IF amplifier of the receiving system.

A variation of this AGC system employs an independent AGC amplifier channel consisting of several stages with greater overall amplification (gain) than does the signal IF amplifier channel. In the system illustrated in (B), the delay voltage is applied to the d-c amplifier stage. Almost all AGC circuits using a d-c amplifier to control the AGC voltage employ a delay diode in the output to prevent the d-c output voltage from ever becoming positive with respect to ground.

AFC

Automatic frequency control (AFC) systems are commonly incorporated into radio or radar



AT.180

Figure 10-28.–Amplified and delayed AGC systems.

receiving circuitry. The purpose of an AFC system is to maintain the appropriate operating frequency of the local oscillator. Oscillators in the UHF and microwave regions have generally poor frequency stability; this instability is often caused by factors which are negligible at lower frequency ranges. Among the major factors are the following:

1. Physical size. The frequency-determining components are necessarily small. Any condition that changes their shape or size causes a change in frequency. Such conditions include vibration, thermal expansion, etc.
2. Frequency pulling. Changes in load cause changes in energy reflections, which effectively means a change in the nature of circuit impedance. The reactive component of the impedance change is combined with the frequency-determining reactances. Thus the operating frequency is also changed. Changes in load may result from such factors as changes in the characteristics of transmission lines, or from reflected energy (echoes) from nearby objects (such as sea return, ECM chaff, aircraft structures, the radome, etc.). Reflected energy changes may also result from variations of the surrounding air (density, moisture content, temperature, etc.).
3. Voltage variations. These variations may be caused either by fluctuations in the primary power source or by poor regulation in the power supply unit of the system.

Because of the inherent frequency instability, it is important that tuning of microwave oscillators be accomplished automatically. For this reason, some type of AFC system is incorporated in all airborne radar sets, and in many other classes of microwave receivers and transmitters. AFC systems are classified in three ways, all according to some aspect of operation. One classification divides AFC systems into single mixer or double mixer classes. A second classification distinguishes the hunting and nonhunting classes. The other classification is according to "absolute frequency" or "frequency difference" operation.

Chapter 11 of this manual, in connection with microwave mixers, contains some information on single ended and double ended mixers. A comparison of that discussion and the information in the present chapter could produce some confusion. As occasionally happens, the same or similar words are used in the classification of two different types of systems. The present discussion is concerned with the operation of AFC systems, which include mixers; the chapter 11 discussion is concerned with the operation of the mixer itself.

All AFC systems require the use of some form of discriminator to detect frequency differences between the oscillator and the reference frequency standard. Also required in all AFC systems is a control circuit to compensate for the difference by shifting the oscillator's frequency.

The type circuitry and provisions for control used in a given set depend on the particular type and specific application of the system.

The following paragraphs present a very brief summary of some important considerations for each of the six basic classes of AFC systems.

Single Mixer

In a single mixer AFC system (fig. 10-29) a portion of the transmitter output is leaked into the mixer, where it beats with the local oscillator signal. The difference frequency (the IF signal) appears at the ouput of the mixer and is then amplified by one or more stages of IF preamplification.

At this point, the IF signal follows two paths—it is further amplified and fed to the detector, and it is also fed into the AFC discriminator. The output voltage from the discriminator varies in amplitude and polarity with changes in the applied frequency.

If the applied frequency (the IF) is at the resonant or center frequency of the discriminator circuit, the output voltage is zero. If the applied frequency is either above or below the desired frequency, the output of the discriminator is either positive or negative depending on the direction of deviation. Voltage magnitude is dependent on the amount of the frequency difference.

The output of the discriminator is then fed to either a d-c amplifier or to some other type control circuit which controls the klystron's reflector voltage. Variations in reflector voltage causes the klystron to shift its frequency of oscillation.

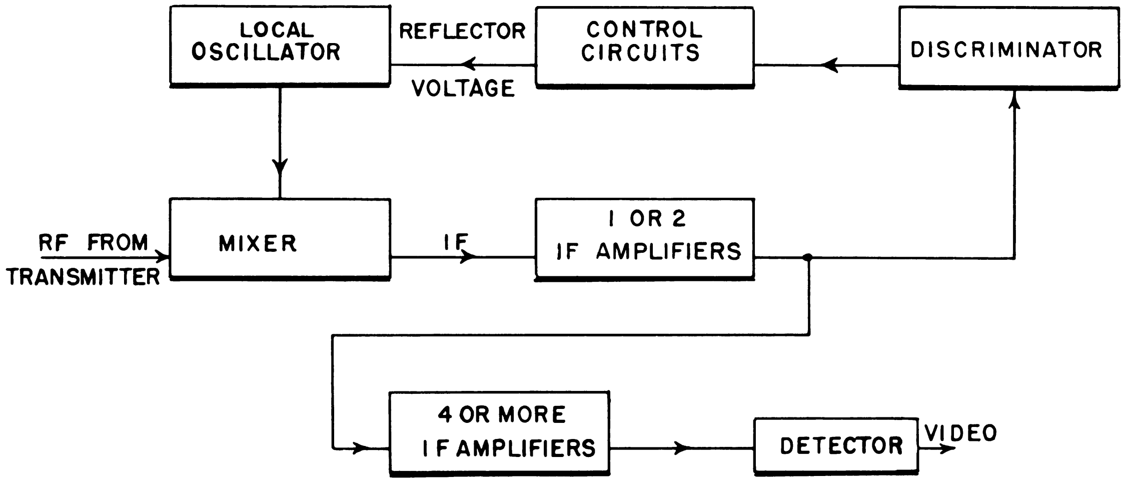


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Figure 10-29.–Single mixer AFC system.

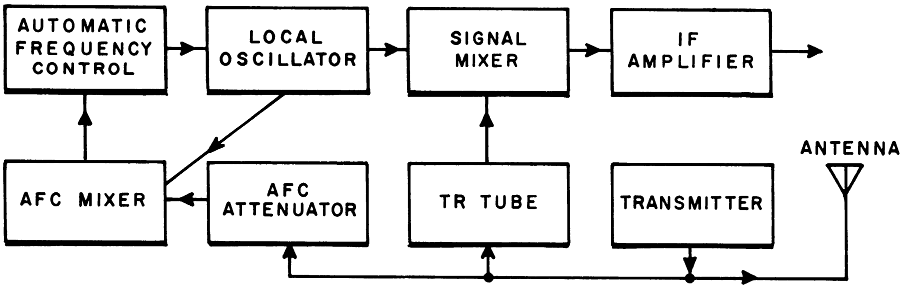
Double Mixer

Most modern radar systems utilize a double mixer AFC system such as that shown in figure 10-30. The separate signal mixer and the AFC mixer are both connected to the same local oscillator. The AFC mixer is coupled to the transmission line through an attenuator which reduces the transmitted pulse and the received echoes by the same ratio. With this arrangement, strong signals from nearby radar, jammers, or sea returns cannot affect the operation of the AFC loop. The double mixer system is similar to the single mixer system, except that the former contains an AFC attenuator and separate IF stages.

Hunting

Almost all radar sets in naval aircraft use the hunting method of AFC. Basically, the hunting system causes the oscillator to sweep through a wide frequency range–wider than the frequency variation range of the radar. This sweep of operating frequency permits the AFC system to find the correct frequency, lock on, and automatically maintain the oscillator on that frequency. This method offers the advantage of automatically locating the new frequency in the event of a sudden large frequency deviation.

Sweeping of the frequency range is usually accomplished by applying a sawtooth of voltage to the reflector of a klystron oscillator. The



AT.182

Figure 10-30.–Double mixer AFC system.

most commonly used sawtooth generators for this purpose are the thyratron and the phantastron, but other types may be used.

A variation of the hunting system utilizes an audiofrequency sine wave superimposed on the sawtooth. This method improves the lockon feature of the basic system and increases the speed of response to frequency shifts. Almost all AFC systems incorporates some type of lockon feature. When the oscillator is operating at the proper frequency, sweeping action is stopped and slight variations are compensated. In the event of a large sudden shift, lock is broken and sweeping is resumed.

Nonhunting

In the nonhunting system, the oscillator is manually tuned to the correct frequency and is then maintained electronically at that frequency. Usage of the nonhumting system is normally limited to equipments where transmission and reception are independent operations (such as single sideband and data link) requiring precise frequency of operation.

Although no sweeping is accomplished, a discriminator is used to detect frequency changes. The discriminator output, in turn, is used to shift the frequency of the oscillator as required, within a narrow allowable frequency range. This method is not usually used in radar systems due to the narrow allowable drift range.

Absolute Frequency

In the absolute frequency system, the operating frequency is determined by a precision frequency standard such as a high-Q cavity. This system is used to maintain the oscillator at the assigned frequency of a transmitter at some remote location. It may also be used to maintain the transmitter at an assigned frequency.

This system has the advantage of permitting reliable reception of intermittent signals with no delay while the receiver searches for the proper frequency. The disadvantage is that the transmitter and receiver must operate on the same frequency, or no reception is probable.

In order to maintain such a precise frequency, eleborate voltage regulation, isolation, and shielding provisions are required. For these reasons, airborne use of this system is not common. Even in data link applications, the frequency difference method is usually employed.

Difference Frequency

In the difference frequency system, the local oscillator is maintained on a frequency which is greater or less than the magnetron frequency. The difference in frequencies is an amount equal to the IF of the receiver. This maintains the tuning of the receiver during search operations.

In normal radar operation, the received echo is of the same frequency as the transmitted pulse (disregarding the slight Doppler shift). Therefore, a fixed tuned IF channel can be used to provide maximum gain. Bandwidth need be only wide enough to cover the normal frequency drift—hunting may be incorporated for unusual shifts.

CHAPTER 11

SPECIAL CIRCUITS AND COMPONENTS

ELECTROMECHANICAL DEVICES

In modern naval aircraft, mechanical and electrical devices for sensing changes in direction and attitude are indispensable. Among the systems which depend upon such devices for their operation are the following:

1. Gyrocompass systems.
2. Flight control systems and autopilots.
3. Radar, camera, and gun platform stabilization systems.
4. Antenna tracking rate measurement systems.
5. Inertial navigation systems.

In addition to sensing devices, aircraft systems require that indications be made available to the pilot, navigator, and operating personnel concerning the operation of many equipments and systems. Many of these indications originate in equipment which must be physically located in places not accessible to the personnel responsible for monitoring them. Electromechanical devices are frequently employed to provide these remote indications.

Among the devices discussed in this section are the synchro, the gyro, the accelerometer, and the servosystem.

SYNCHROS

A synchro is an electromechanical analog converter. It may, through inductive means, give an electrical output which is a function of its rotor position; or it may position its rotor to an angle which is a function of the electrical input. The term synchro, as it was originally used in the Navy, included a category of induction devices. The term is now used rather loosely in general application. According to the military specification, however, proper use of the term is limited to one of five types of devices, as listed below.

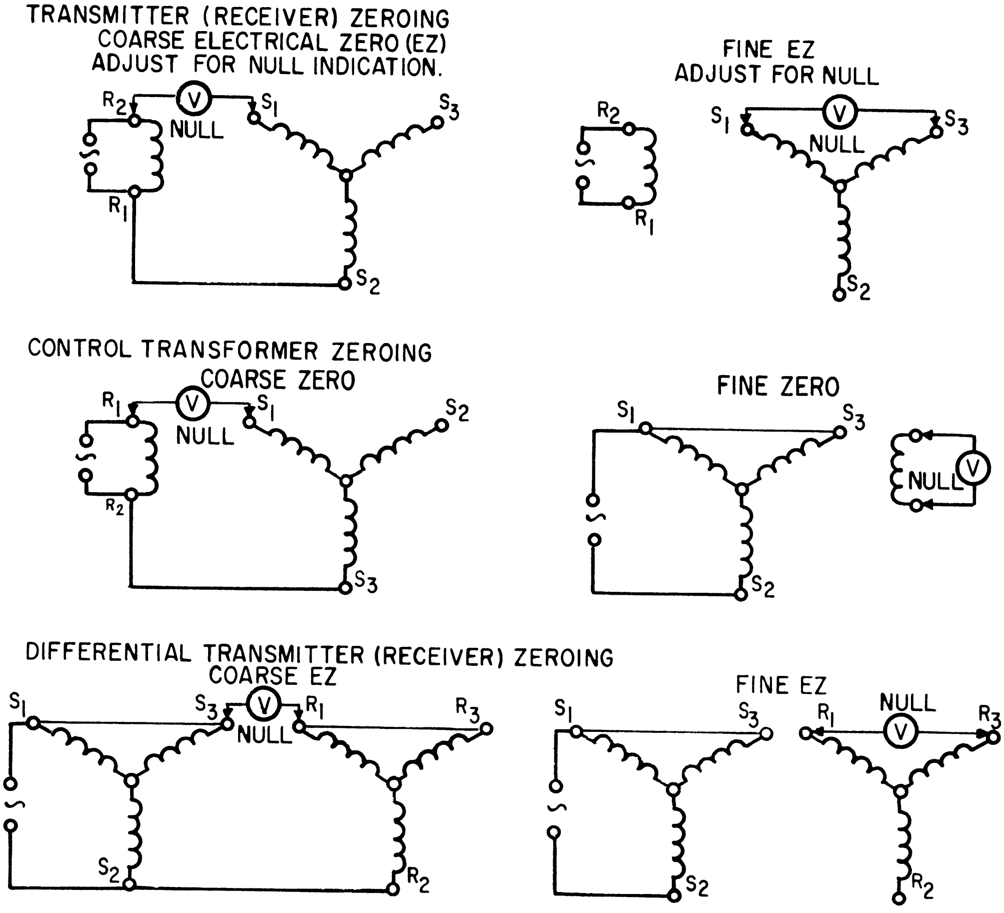
1. Synchro transmitter—converts a mechanical input (rotor position) into an electrical output.
2. Synchro receiver—converts an electrical input into a rotor position (mechanical output).
3. Synchro differential transmitter—gives an electrical output which is a function of two inputs, an electrical input and its rotor position.
4. Synchro differential receiver—gives a mechanical output which is a function of two electrical inputs, the primary and secondary.
5. Control transformer—gives an electrical output, with a varying magnitude and polarity, which depends on the relative position of the rotor and stator.

Theory of Operation

A basic introduction to synchros is presented in chapter 19 of Basic Electricity, NavPers 10086-B. The discussion presented in the following paragraphs is intended to summarize the basic manual and to present additional details and data of practical use to the technician.

In normal operation, a synchro can be treated as a complex transformer in which the coupling coefficient is proportional to the cosine of the angle between the primary and the secondary. All synchros use a WYE connected stator winding. The rotor is either a WYE or a single winding, depending on the device.

A synchro is a single phase, 60- or 400-hertz device. The output voltages, line to line, are either in phase or 180° out of phase with the rotor voltage. The three-line-to-line stator volt-


TRANSMITTER (RECEIVER) ZEROING
COARSE ELECTRICAL ZERO (EZ)
ADJUST FOR NULL INDICATION.
R2
V
S1
S3
NULL
R1
S2
FINE EZ
ADJUST FOR NULL
R2
S1
V
S3
NULL
R1
S2
CONTROL TRANSFORMER ZEROING
COARSE ZERO
R1
V
S1
S2
NULL
R2
S3
FINE ZERO
S1
S3
NULL
V
S2
DIFFERENTIAL TRANSMITTER (RECEIVER) ZEROING
COARSE EZ
S1
S3
V
R1
R3
NULL
S2
R2
FINE EZ
S1
S3
R1
NULL
V
R3
S2
R2

AT.183

Figure 11-1.–Electrical zeroing procedure.

ages uniquely identify a single electrical angle between 0° and 360°.

In order to identify the electrical angle, an arbitrary electrical zero (EZ) has been chosen for each device. (See fig. 11-1.) This electrical zero is an internal reference–the angle that the rotor makes with respect to the stator under specified conditions.

If a voltage of known amplitude and frequency is impressed on the rotor of a synchro, the voltages induced in the stator describe a single angle. This mechanical-to-electrical analog is the principle of the synchro transmitter. If these three voltages are applied to the stator terminals of a synchro, the voltage induced in the secondary (rotor) is proportional to the sine of the difference between the electrical angle represented by the stator voltages and the mechanical rotor angle.

In the synchro control transformer, the output voltage is normally supplied as an error signal driving a device which turns the rotor. The rotor continues to be turned until the synchro's electrical angle coincides with the input (command) angle. At this position the output voltage of the transformer drops to zero.

In the synchro receiver, the secondary (rotor) is connected to the same a-c excitation as the transmitter. The two synchros, transmitter and receiver, are connected in parallel. When both rotors make the same electrical angle, identical voltages are induced in the respective transmitter and receiver stator windings. Since the voltages are identical, no current flows in the external wires or in the stator winding; therefore, no magnetic field is induced. If the rotors do not make the same angle, the voltages induced in the transmitter stators are different from those in the receiver stators, and currents flow, creating an associated (stator) magnetic field in both synchros. The magnetic field of the rotor, interacting with the magnetic field of the stator, attempts to turn the rotor until the fields coincide. If the transmitter rotor is not permitted to turn, the receiver rotor turns until the turning force reaches zero. Both torque arm and magnitude decrease as the error angle–the difference between the transmitter and receiver angles–approaches zero. At angles near zero, only a weak magnetic field is induced by the stator currents; therefore, to prevent overshoots and resulting oscillations, receiver rotors are provided with additional mechanical damping.

The chief difference between synchro units is in rotor design; each device is designed to have the best electrical properties when connected into the system in the expected manner. Any one of them could be connected as either of the others (transmitter as receiver or transformer, etc.), but with attendant problems such as hunting or decrease in accuracy and speed.

The differential transmitter and the differential receiver have a WYE connected rotor as well as a WYE connected stator. They are designed to supply an output angle which is the sum, or difference, of two input angles; the differential transmitter combines an electrical and a mechanical angle to furnish an electrical output. The receiver combines two electrical inputs to furnish a mechanical output. As in the other synchros, the major difference between the transmitter and the receiver is in rotor construction, the receiver rotor being designed to provide increased damping.

When the stator is excited by voltages normally supplied by a synchro transmitter, voltages are induced into each of the rotor windings. The voltage induced into each secondary winding varies with mechanical displacement in the same manner as in a regular synchro, except that in this case there are three outputs, displaced 120° electrically from each other.

The primary input voltages to the stator create a resultant magnetic field. Changing the input voltages to indicate a different angle will change the orientation, but not the magnitude of the resultant field. It is thus possible to have this primary field represent any angle with respect to zero. At the same time, it is also possible to position the rotor, causing the output electrical data to be advanced an electrical angle equal to the mechanical deviation from electrical zero.

In the differential receiver, the stator and rotor fields form a magnetic couple as in the synchro receiver. (Each field inside the case may be considered as that of a simple bar magnet.) The rotor will turn, if free to do so, until the two fields are alined.

System Alinement

Since the stator is normally fixed with respect to the case, the internal reference is easily extended by turning the case until the electrical zero angle coincides with a convenient external reference point. In a particular system this point may be identified by a scribe mark, by a locking pin, by an optical sight arrangement, or by a zero reading on a dial or gage. The particular means used is not important, except that the adjustment can be repeated with greater accuracy in some kinds of systems than in others.

All synchros in a system having an external reference should be alined to that reference. Not infrequently, systems are "adjusted" by turning any intermediate device until the output indication agrees with the input. When a unit is changed, angular agreement is lost, to be regained by turning the case of a convenient synchro. This solution requires only one step to aline the synchro system each time a component of the system is changed. It may be acceptable if useful data is taken out of the system at only one point.

If a number of outputs are taken from different points in the system, it becomes imperative that the system be properly alined and that all components indicate proper angles at all times, rather than a + 15° error at one point in the system balancing a -15° error some place else in the system. This can be done either by completely alining the system, starting at a known good zero reference and working toward the final transmitter, or by establishing an external standard and insuring that all synchros are properly zeroed to this standard prior to installation. This second solution becomes very tricky if there are any mechanical linkages required in the installation; if all linkages are electrical, a synchro will automatically indicate the correct angle when installed.

GYROS

Although every spinning object exhibits some gyroscopic properties, a true gyroscope is a complex item designed and mounted specifically to utilize these properties. Several types of gyros have been developed for various applications. Although each type exhibits its properties in a somewhat different manner, all operate on the same basic principle.

Basic Principles

Every object possess inertia; it tends to maintain its present position if at rest, or to continue in uniform motion if moving. A moving body also possess momentum; the amount of momentum depends on the mass of the body and its velocity. A body possessing circular motion (a revolving body) must maintain a balance of forces in order to revolve in a uniform path. A rotating mass represents a special type of revolving body, where the center of mass and the center of revolution coincide. Basically, a gyroscope is a spinning mass which has a high mass-to-size ratio and a high speed of rotation.

The spinning mass, called the rotor, is in itself the gyroscopic element. It is mounted in such a manner that the friction at all points is kept as small as possible, and is equally distributed to present balanced forces acting on the common centers of mass and rotation.

Figure 11-2 illustrates a demonstration gyro used to explain and demonstrate gyroscopic terms, principles, and operation. This figure should be used for reference throughout the following discussion of the basic gyro. (The rotor shaft mentioned previously is actually the spin axis.)

The rotor is mounted so that it is free to spin on its axis. As the rotor spins, its momentum increases with an increase in rotational speed. Each particle of the rotor which is not located on the axis of rotation possesses some momentum, depending on its mass and its linear velocity. The total momentum of the rotor is the total of the momentum forces on all particles. Figure 11-3 and the subsequent discussion show how the distribution of rotor mass affects rotor momentum. The three rotors shown are assumed to have the same specific density (mass-to-volume ratio), equal mass, and equal angular velocity.

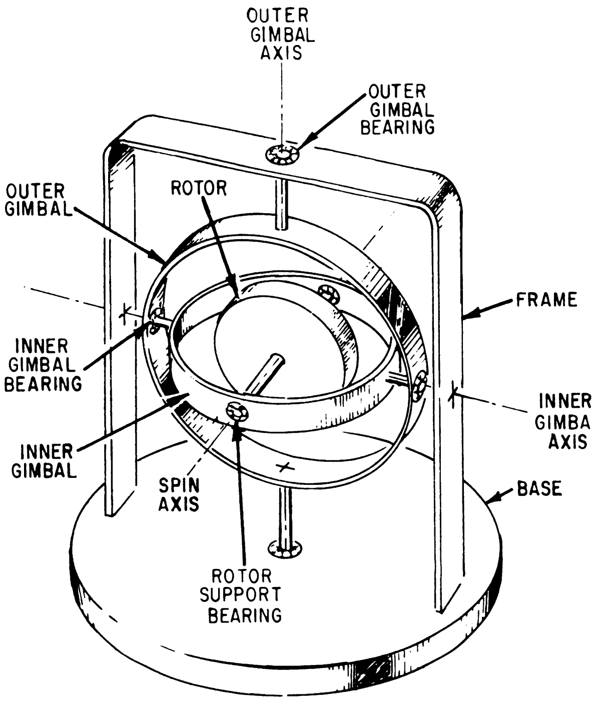


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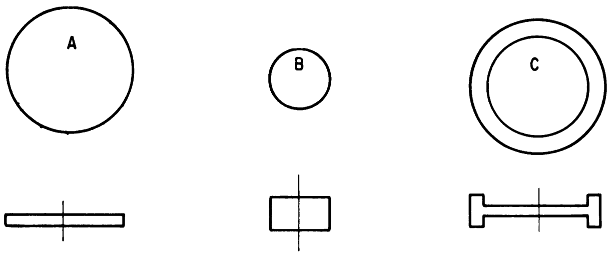
Figure 11-2.–Demonstration gyro.

As previously stated, momentum varies directly with both mass and linear velocity. Since in the present discussion the mass of each rotor, as well as the mass of each particle of each rotor, is assumed to be equal, mass may be disregarded in the following comparisons.

Linear velocity varies directly with the angular velocity and with the effective radius of rotation. In the current discussion, the angular velocity (revolutions per second) is assumed to be the same for each rotor, and may



AT.185

Figure 11-3.—Effect of rotor design on momentum.

therefore be disregarded. Thus, for the three rotors shown in figure 11-3, a comparison can be made on the basis of the effective radius of rotation.

Rotor A (fig. 11-3) is a thin disk with a comparatively large radius and uniform thickness. In this instance, the effective radius is equal to one-half the radius of the rotor (due to the uniform distribution of particles). Rotor B also has uniform distribution of particles; but due to its shape (thick and with a comparatively small diameter), its effective radius is somewhat smaller. This rotor possesses less momentum than rotor A at the same angular velocity.

Rotor C, on the other hand, does not have a uniform distribution of its mass. Due to its shape, the particles are concentrated toward the outer rim, and the effective radius is somewhat more than one-half radius of the rotor. A rotor with this shape would normally have greater momentum than either of the others illustrated.

In effect, the momentum of the rotor acts in a plane which contains the center of rotation and the orbit of the average particle of the rotating mass (the plane of rotation).

The rotor must be built so that the plane of rotation is perpendicular to the spin axis. As shown in figure 11-2, the rotor shaft is supported by low friction bearings mounted in the rotor support. The momentum of the rotor acts to maintain rotation within the plane. It resists any attempt to change the plane of rotation by tilting the spin axis to an angle not perpendicular to the original plane. A stationary gyro is relatively free to move in any direction as long as the spin axis maintains its perpendicular relationship with respect to the original plane of rotation.

Properties of Gyroscopes

DEGREE OF FREEDOM.–A rotor mounted in a rigidly fixed support would serve no useful purpose. A practical gyro must be constructed in such a manner that the base can be maneuvered or changed with respect to the spin axis and the plane of rotation. When the base is rotated in such a direction that the plane of rotation is not changed, the gyro is said to possess FREEDOM in that direction.

Gyro freedom is provided through the use of GIMBALS (fig. 11-2). A gimbal is a supporting structure that is able to revolve so as to provide the gyro with a DEGREE OF FREEDOM. A gyro having two degrees of freedom is able to maintain its plane of rotation regardless of the movement of the base, and is called a FREE gyro. Free gyros require two gimbals.

The term "degrees" of freedom must not be confused with angular measurements. As applied to gyros, the term indicates the number of directions in which the base may be rotated without disturbing the plane of rotation.

In figure 11-2 note that each gimbal is supported through an axis which is perpendicular to the axis of the element which is supported by the gimbal. Each gimbal is mounted in low friction bearings to provide greater precision and less opposition to desired motion.

RIGIDITY.–As previously discussed, one of the basic properties of the gyroscope is its opposition to any change in its plane of rotation. It tends to maintain a fixed position in space. This property is called RIGIDITY. A gyroscope possesses rigidity because of, and in an amount directly related to, the momentum of its rotor. Gyroscopic rigidity is not absolute, however; the plane of rotation can be changed in several ways.

PRECESSION.–If a force is applied to the rotor shaft, the spin axis of the gyro may be tilted. The tilting represents rotation of the axis, and occurs in the manner shown in figure 11-4 and described in the following paragraph.

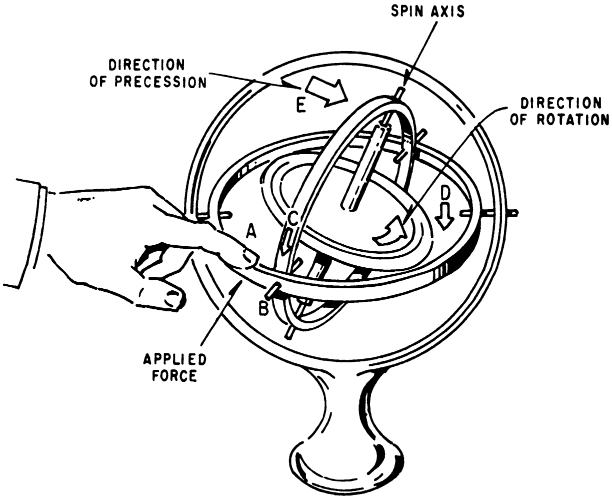


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Figure 11-4.–Gyroscopic precession.

A downward force applied to the outer gimbal at point A is transferred through pivot B to the inner gimbal, and is felt as a downward force at point C. The downward force on the inner gimbal at point C, in turn, travels 90° in the direction of rotation and causes a downward movement of the rotor at point D. This downward movement of the rotor at point D represents a rotation of the spin axis in the direction indicated by the arrow at point E. This rotation of the spin axis is called precession.

The property of precession is closely associated with the property of rigidity. The two properties are mutually dependent; a gyro does not possess rigidity if it does not precess, and a precessing gyro always offers some amount of rigidity.

The tilting force which causes a gyro to precess is called a TORQUE. It acts at some distance from the center of gravity, and has a magnitude which depends on the amount of force and the distance at which it is applied. It produces angular displacement of the spin axis (and the plane of rotation); angular displacement is a partial rotation. Precession of a gyro is always a reaction to an applied torque. (One cannot precess a gyro—one can only apply a torque that will cause a gyro to precess itself.)

A force applied to the rotor at its center of gravity does not tend to precess the gyro. A spinning gyro can be moved in any direction as readily as a gyro at rest, provided the spin axis remains parallel to its original position in space. (This type of motion is called TRANSLATIONAL motion.) Because of this feature, a gyro cannot provide stabilization in planes perpendicular to the spin axis—the gyro makes no response to motion in these directions. For complete stabilization in aircraft, two gyros, with their spin axes perpendicular to each other, are required. Motions which do not affect one gyro produce the necessary response in the other. The dual installation permits the establishment of reference lines from which any changes in pitch, yaw, or roll may be measured.

Thus far the discussion of precession has centered on the precession of a gyro as viewed in relation to its established position in space. This is referred to as REAL precession. A free gyro which is stationary with respect to a fixed point on the surface of the earth exhibits an additional property called APPARENT precession. Rigidity fixes the spin axis in space; the earth, which is rotating, revolves around the rotor. Thus, as viewed from its fixed position on the surface of the earth, the axis of the gyro appears to tilt (or precess) at a rate which corresponds to the rate of rotation of the earth about its spatial axis.

Apparent precession makes a completely free gyro unfit for use as a reference for earthbound equipment over an extended period of time. To compensate for apparent precession, an ERECTING mechanism is normally incorporated to maintain the spin axis in a fixed position relative to the earth's surface.

DRIFT.—The gyro spin axis does not always point in the direction it theoretically should. This error in the gyro is produced by random inaccuracies in the system. The resulting change in position of the spin axis is called DRIFT. There are three general sources of drift in a gyroscope, as follows:

1. Imbalance. A gyroscope often becomes dynamically unbalanced when operating at a speed or temperature other than that for which it was designed. Some imbalance exists in any gyro since manufacturing processes do not give perfect symmetry.
2. Bearing friction. Friction in the bearings of the gimbals results in lost energy and incorrect gimbal positions. Friction in the spin axis bearing causes drift only if the friction is not symmetrical; an even amount of friction all around in a bearing results only in a change of the rate of rotation.
3. Inertia of gimbals. Energy is lost whenever a gimbal rotates because of the inertia of the gimbal. The greater the mass of the gimbal, the greater the drift from this source.

Complete elimination of drift in gyroscopes appears to be impossible. However, great strides have been made in recent years twoard reducing the amount.

Types of Gyros

A gyro is a bilateral device. If a torque is applied, the gyro precesses at an angular rate proportional to the magnitude of the applied torque. If a gyro is caused to precess at an angular rate, the gyro develops a torque which is proportional to the rate of precession. This feature indicates the two basic types of gyros—distinguished mainly by the input and output devices.

DISPLACEMENT GYRO.–This type of gyro is used to measure angular displacement of the base mounting from an established reference line. The reference line is established by the spin axis and is maintained fixed by the rigidity of the gyro. In aircraft gyro systems, motion of the aircraft with respect to sensitive axes (roll, pitch, and/or yaw) results in angular displacement of the gimbals with respect to the spin axis and plane of rotation. Angular displacement is measured by means of synchros, potentiometers, capacitive or inductive bridges, etc. The device used to detect angular displacement and develop the error signal is called a PICKOFF.

RATE GYRO.–A rate gyro usually has a single degree of freedom, and is subjected to an angular rate about its sensitive axis as illustrated in figure 11-5. In response to displacement in the sensitive (quadrature) axis, the gyro develops a torque which is proportional to the rate of angular displacement. Instead of allowing complete freedom of motion about the gimbal axis, the rate gyro has a restraining device (spring). The gimbal is able to rotate about its axis only until the restraining force becomes equal to the torque developed by the gyro. A pickoff arranged to measure the angular displacement of the gimbal axis may be used to measure the angular rate of the input.

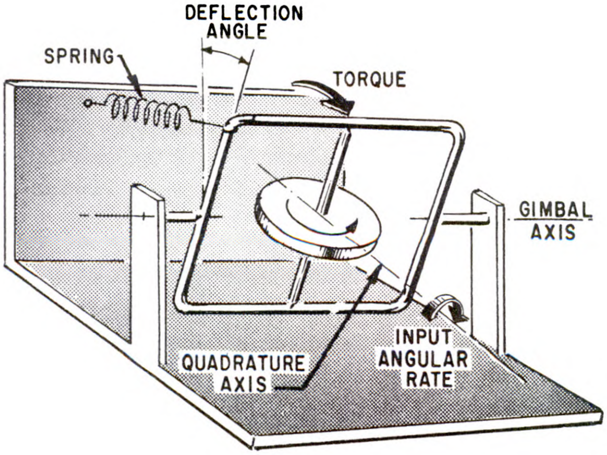

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Figure 11-5.–Simplified rate gyro.

ACCELEROMETERS

Accelerometers have been used for many years, but until the last few decades they were used mainly in laboratories. They are now in common use as a means to measure an aircraft's rate of change or deviation from its planned course. They are used in conjunction with autopilots, inertial navigation systems, etc. They are also used to help the pilot land his aircraft by indicating the vertical acceleration. An additional use of the accelerometer is to judge the amount of dynamic and aerodynamic force imposed upon the pilot.

Acceleration can be defined as the rate of change of velocity of a moving object with respect to time. Velocity is the rate of change of distance with respect to time.

An example of a simple accelerometer is shown in figure 11-6. Although this is a simplified version, the basic accelerometer principles may be observed. When there is no acceleration (as shown in (A)), the two springs attached to the mass maintain the mass in the center, or null, position. Therefore, the meter indication is zero.

If an application of force causes the accelerometer housing to move suddenly from left to right, the mass (conforming to Newton's law) tends to remain stationary. This causes the meter needle to pivot about its axis and give the indication shown in (B). When the force is no longer applied, the springs again center the mass and the meter returns to zero. Conversely, if the force is applied from the opposite direction, the same principle causes the mass to react in the same manner, but with the opposite indication on the meter. The damper pistons and cylinders

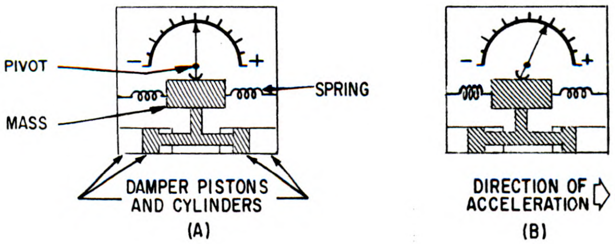

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Figure 11-6.–Simplified accelerometer.

prevent vibration and over sensitivity of the accelerometer by damping transient movements.

Vertical Reference Accelerometer

Figure 11-7 is a mechanical schematic of a vertical reference accelerometer currently used in naval aircraft. The three pointers on the face of the dial indicate instantaneous negative or positive vertical acceleration as well as the maximum acceleration in either direction during any selected period of time. With the aircraft in level flight, the instantaneous acceleration pointer reads positive 1 G.

As illustrated in the schematic, vertical movement of the mass causes the cord-pulley assembly to move. This turns the main pointer shaft and rotates the main pointer. As the shaft rotates, the main pointer driver arm moves toward one of the auxiliary pointer driver arms. If the G force is larger than any previously encountered, the two driver arms make contact

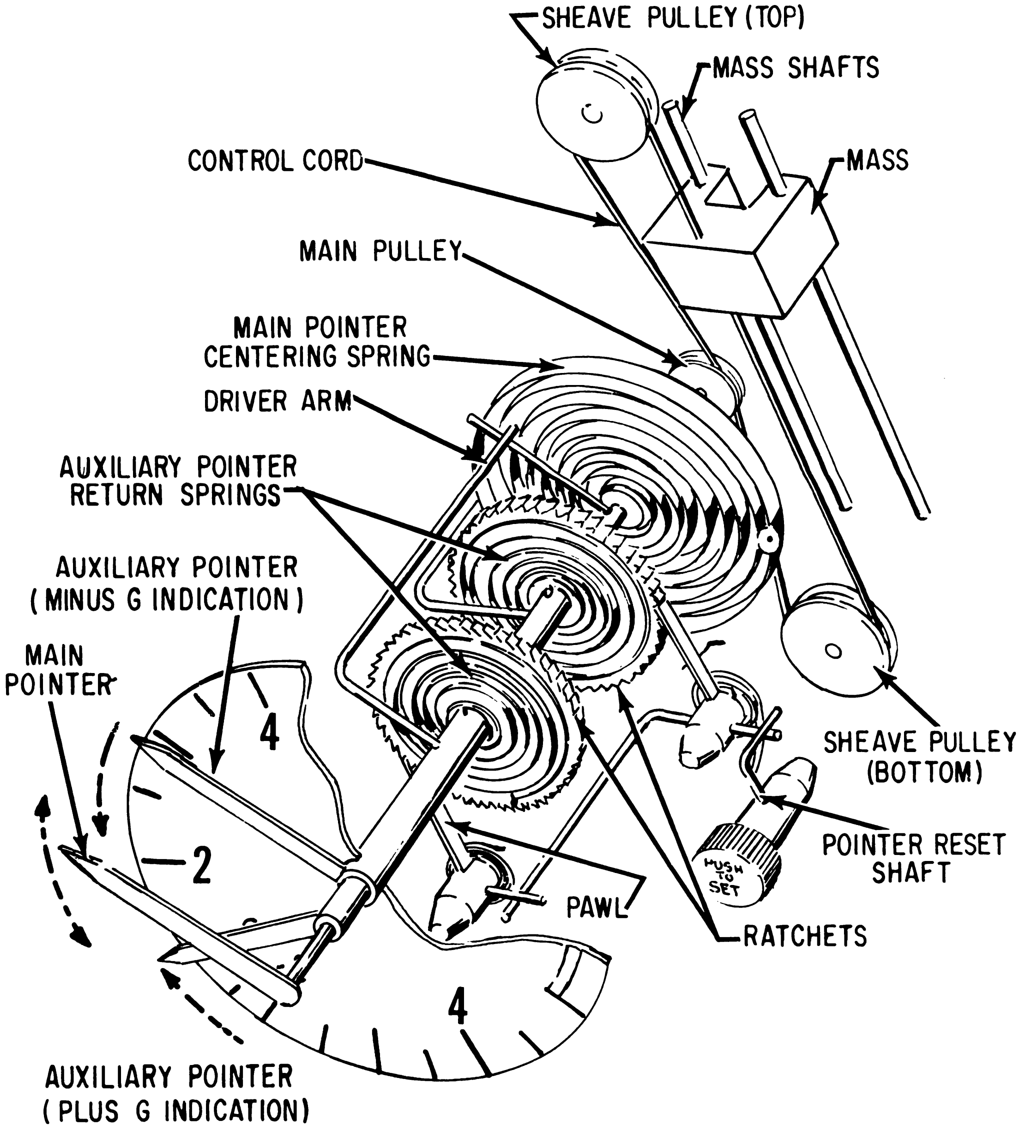

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Figure 11-7.–Vertical reference accelerometer.

and the auxiliary pointer is driven in coincidence with the main pointer.

As the auxiliary pointer rotates, the pawl slides over the ratchet teeth; but when the G forces start to diminish, the pawl engages one of the ratchet teeth and holds the auxiliary pointer at its maximum excursion of travel. This indicates the maximum G force in that particular direction. The RESET knob on the face of the instrument allows the pointers to be returned to the null position when desired. It should be noted that the direction of vertical acceleration determines which auxiliary pointer will rotate.

Force Balance Accelerometer

An accelerometer commonly used with inertial navigation systems is the force balance accelerometer. A schematic representation of this type is shown in figure 11-8. The pickoff coil, the mass, and the torquer coils are all situated on a common movable shaft, which has the ability to make a partial rotation about its pivot point axis.

With zero acceleration, the induced current in the pickoff coil is balanced and the torquer coils keep the mass in the null position. However, as acceleration occurs, the mass velocity tends to remain constant. Since the stationary portion of the accelerometer assumes the new velocity, it causes one of the exciter coils to move closer to the pickoff coil and the other exciter coil to move farther away. Which exciter coil comes nearer to the pickoff coil depends upon the direction of acceleration. As the distance changes between the exciter coils and the pickoff coil, an unbalanced condition occurs in the pickoff coil circuit. This causes an error signal to be induced, which is amplified, changed to d.c., and applied to the torquer coils. Windings of all the coils are such that any unbalanced condition in the circuits produces a bucking (or reverse) current which counteracts the field of the torquer magnets and keeps the mass near mechanical zero. As the acceleration force increases, the amount of current necessary to keep the mass near the null position also increases. Since the current is proportional to the acceleration, the voltage drop across Rp, a precision resistor, is also indicative of acceleration. This voltage drop, E_{R_p}, then becomes the electrical output from the accelerometer. It can then be supplied to flight control systems as a function of acceleration.

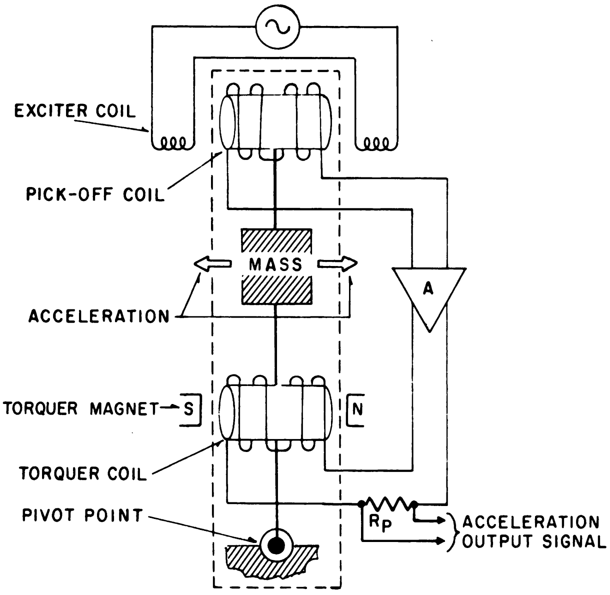

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Figure 11-8.–Force balance accelerometer.

Pulse Counting Accelerometer

Though the output of a force balance accelerometer is an analog current proportional to acceleration, there is need for accelerometer output signals to be in digitalized form. Pulse counting accelerometers satisfy this need, since their pulse output can be supplied directly to computers. A schematic of a pulse counting accelerometer circuit can be seen in figure 11-9 (A), while the cutaway view is shown in figure 11-9 (B).

With velocity remaining constant, the brush spring holds the mass at null and the brush rests on the reset contact of the switch. As acceleration occurs, the tendency of the mass to remain at a constant velocity causes the spring to compress. In doing so, it allows the brush to move off the reset contact; and if acceleration is great enough, the brush will pass over the switch contacts for acceleration levels 1, 2, 3, and 4. These levels are determined by the stiffness of the spring.

As the brush passes over each contact (in a positive direction), an output pulse from each contact is coupled to one of four counters. This advances the counter one-half count. The accelerometer is so designed that as acceleration decreases and the mass tends to assume the new velocity, the counters will not advance the remaining half count until the brush once again touches the reset contact. With this type of pulse output, it is possible to record each time gravity forces have reached a predetermined level.

Applications

There are many types of accelerometers in use today; the examples given constitute only three of them. However, since the basic principle that a mass in motion tends to remain in motion and one at rest tends to remain at rest applies to all accelerometers, all of them can be considered similar.

Vertical reference accelerometers are used to measure either position or negative acceleration, while the counting accelerometer determines vertical movement in one direction only. Force balance accelerometers aid in determining an aircraft's present geographical position in relation to its previous geographical position. This is accomplished by computing the aircraft's acceleration in both the North-South and East-West directions. The aircraft's navigation system combines this information with other inputs to determine the distance the aircraft has traveled and the direction of travel from a previous position.

MAGNETIC COMPONENTS

A basic coverage of magnetism and magnetic properties and components is presented in Basic Electricity and in Basic Electronics. The discussion in the current chapter is devoted to some of the specific details and applications of primary interest to personnel involved in maintenance of avionic equipment which make use of these devices.

Both permanent magnets and electromagnets are employed in airborne electronic equipment. A few of the many specific uses of permanent magnets are in the focusing of CRT electron beams, in the rotors of electric generating devices, in variable reluctance pickoff devices, and in magnetrons. A few of the many specific applications of electromagnets are in relays, in CRT deflection systems, in rotating electrical devices, and in magnetic amplifiers.

The main distinction between the two basic types lies in the fact that electromagnets retain their magnetic properties only while the electrical energy is applied; the permanent magnet requires no electrical energy in order to retain its magnetic state.

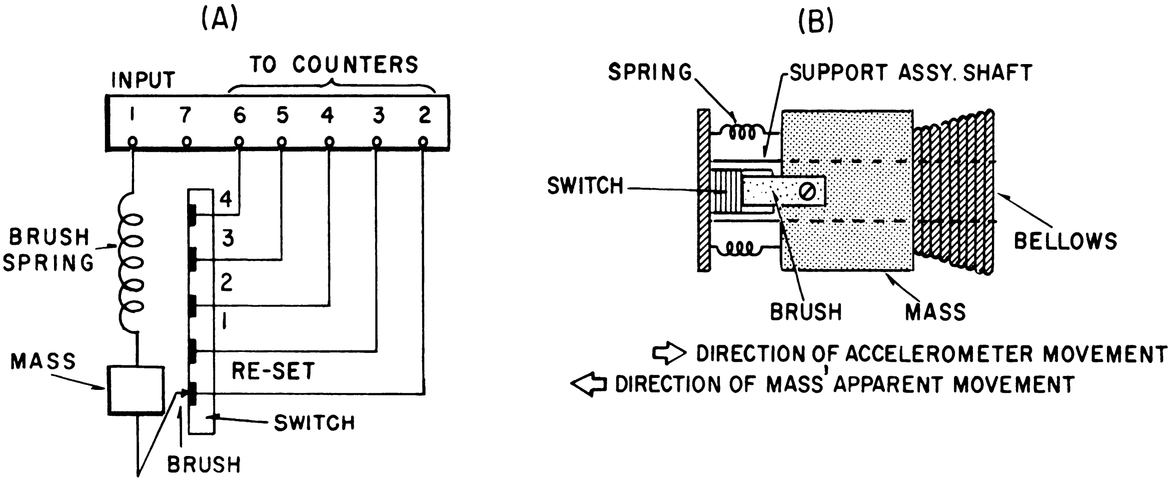

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Figure 11-9.—Pulse counting accelerometer.

FERRITE MATERIALS

Magnetic materials are those materials which, either as their natural condition or due to some external influence, possess magnetic properties. The term FERRITE is applied to that portion of the latter group which possesses specific useful characteristics. Ferrites are hard, brittle, crystalline materials produced from a mixture of powdered materials including iron oxides.

By altering the mixture, ferrites may be developed to exhibit a variety of magnetization characteristics. Some ferrites are well adapted for use at low frequencies (such as magnetic amplifier cores and memory cores in computers), but are not usable at high frequencies (especially those frequencies falling in the microwave region). Microwave ferrites will be discussed in a later section of this chapter; the current discussion is limited to those ferrites used in lower frequency ranges.

The basic theory of magnetization is presented in Basic Electronics. Although that discussion is concerned primarily with general magnetic materials, it is equally applicable to ferrites. As mentioned previously, ferrites are a special class of magnetic materials developed to exhibit special characteristics.

Ferrites are classified in accordance with the special characteristics they exhibit. These characteristics include the relative and specific B-H relationships, flux densities attainable, eddy current and hysteresis losses, residual losses, permeability, temperature coefficient, and magnetic retentivity. For practical usage, the ferrite material is selected on the basis of the values of these characteristics required in the particular application.

Table 11-1 illustrates some practical applications of ferrite materials at low frequencies, and lists the properties of each. In this table, Q is a figure of merit representing the energy ratio of useful conversion (into magnetic energy) to losses.

MAGNETIC AMPLIFIERS

Magnetic amplifiers, as the name implies, are amplifiers which operate through magnetic properties rather than electron tube principles. In aviation electronics applications, their major function is as a servomechanism control device. As an amplifier, this device permits the use of a small control signal to govern the operation of a much larger device requiring considerable power.

A typical magnetic amplifier consists of multiple windings on a common core. (See fig. 11-10.) Under static (no signal) conditions, the core is partially saturated by the flow of a d-c current in one of the windings (bias). An error signal (either a-c or d-c voltage) applied to a second (control) winding varies the degree of saturation, thus changing the permeability of the core. The changing permeability controls the flux cutting the third (load) winding, and permits the change in magnitude and instantaneous polarity of the voltage applied to the servomechanism to control the direction and speed of correction.

In closed loop servosystems, the magnetic amplifier has a fourth (reference) winding which applies the feedback signal to the system. This system improves circuit operation by decreasing the hunting effect and canceling the error input when actual operation of the load coincides with the desired operation.

Magnetic amplifiers used in airborne electronic equipment are of many different configurations, depending on specific application. The saturable current potential transformer is one type of magnetic amplifier.

Magnetic amplifiers may be broadly classified as belonging to the saturable reactor type or to the self-saturation type. These two types are discussed very briefly in the following paragraphs. If more details are desired a comprehensive discussion is available in a series of articles appearing in the DIGEST during 1963 and 1964. Reprints of this series are also available in booklet form.

Saturable Reactors

A magnetic amplifier is classed as a saturable reactor if the individual load currents are bidirectional, even though the load circuit may employ rectifiers to operate a d-c operated load.

The reactor core normally has a rectangular B-H loop. The no-signal flux is established by the d-c bias winding; the error signal is applied in series with this d-c to vary the degree of saturation. This combined signal and biasing ar-

Table 11-1. —Summary of ferrite applications.

Type of components	Typical frequency	Characteristics desired
LINEAR B-H CHARACTERISTICS:		
Filter inductors	100 kHz	High Q, precision, stability, low modulation.
IF transformers	465 kHz	High Q, stability, adjustability.
Antenna cores	1, 000 kc to 15 mHz	Moderate Q, stability.
Wideband transformer	1, 000 kc to 15 mHz	Reproducible transmission properties.
Adjustable inductors	Various	Adjustment range 20 percent.
Tuners	Various	Adjustment range greater than 10:1.
Miniature inductors	Various	Moderate Q, small size.
Loading coil	Voice	Stability, low modulation, low flux leakage.
NONLINEAR B-H, MEDIUM TO HIGH FLUX DENSITIES:		
Flyback transformers	15-100 kHz	Low losses, moderate size, retentivity, high Curie temperature.
Deflection yokes	Pulse	Same as above.
Miniature transformers	Pulse	Small size, easy mounting.
Carrier power transformers	Various	Low eddy current, high μ, high resistive impedance.
Supression heads	Various	Same as above.
Recording heads	Various	Very high μ, low eddy current, mechanical rigidity.
HIGH NONLINEAR, RECTANGULAR LOOP:		
Memory cores	Pulse	Two stable states, fast flux reversal, low eddy current.
Switching cores	Pulse	Fast flux reversal, high output.
Multiaperture cores	Pulse	Fast flux reversal, low eddy current.
Magnetic amplifiers	Various	High μ, up to saturation, almost horizontal B-H line above saturation.
MAGNETOSTRICTION AND OTHER PROPERTIES:		
Delay lines	Pulse, various	Low B's are acceptable, high μ at high frequencies.
Filters and oscillators	100 kHz	Same as above.
Temperature controls	Various	Sensitivity to temperature.
Transducers	20-30 kHz	High power outputs, mechanical strength.

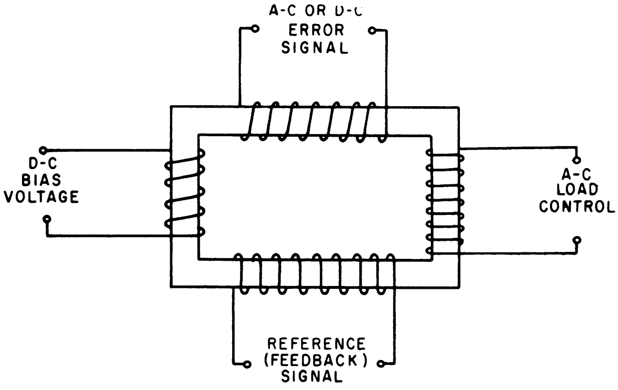

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Figure 11-10.–Typical magnetic amplifier, simplified.

rangement controls the permeability of the core, and thus the inductive reactance of the a-c load winding. The inductive reactance of the a-c load winding, in turn, governs the power applied to the load. (See fig. 11-11.) Control of a d-c load requires the use of rectifiers in series with the load (not shown).

Self-Saturating Reactors

A magnetic amplifier is of the self-saturating type if the individual load currents are unidirectional, being gated on and off by rectifiers for some period less than one-half the a-c voltage cycle. The major difference in the construction of the self-saturating reactor (fig. 11-12) and the saturable reactor (fig. 11-11) is the addition of the rectifier in the load circuit and the reversal of the bias voltage. Differences in operation, however, are somewhat more extensive.

The self-saturating magnetic amplifier is limited in use to d-c loads, but is capable of a much higher gain. Instead of merely increasing or decreasing the flux, the self-saturating amplifier is capable of changing the flux from almost zero to nearly complete saturation.

INDICATORS

Many different types of indicators are used in airborne electronics equipment for numerous purposes. The indicators of greatest concern to the technician use the cathode-ray tube to furnish a visual display. Other important types of indicators include the various meters, dials, etc., used in test equipment, computers, communications equipment, electronic navigational aids, and radar applications.

CRT DISPLAYS

Basic discussions of the cathode-ray tube and its applications and associated circuitry appear throughout Basic Electronics and the present manual. Basic Electronics presents information on the CRT itself and its applications in oscilloscopes and synchroscopes, some of the major types of scans used in radar equipment, and the sawtooth generators which develop sweep voltages. The present manual presents discussions of many of the circuits used in CRT indicators and numerous actual applications of the CRT indicator in operational and test equipment. The cathode-ray tube indicator, therefore, is not discussed in detail at this point.

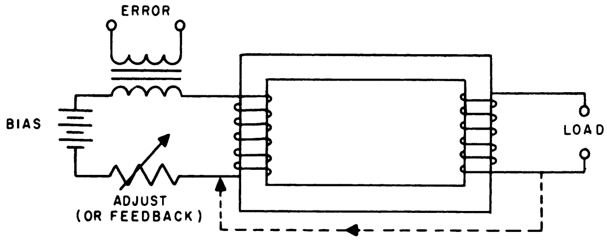

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Figure 11-11.–Saturable reactor type magnetic amplifier, simplified.

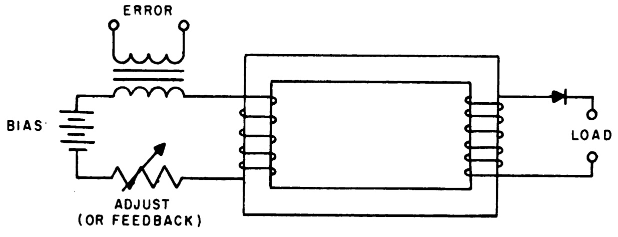

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Figure 11-12.–Self-saturating magnetic amplifier, simplified.

OTHER INDICATOR TYPES

Indicators may be classified in many different ways. One method of classification is based on the affected sense. Technicians are concerned with two classes–visual and aural. Since aural indications are comparatively unreliable for accurate interpretation, their use is limited to rough analyses of loudness and intelligibility. This discussion, therefore, is limited to visual indicators.

Visual indicators are also classifiable by many systems. For this discussion, classification is based on the basic operating principle of the device. A listing of the types of indicators would include the following classes, as well as many others:

1. Lights.
2. Rotary counters.
3. Linear displacement mechanisms.
4. Direct angular displacement devices.
5. Remote angular displacement devices.

Lights

Indicator lights are commonly used to indicate the operating status of circuits or equipment. Many items of test equipment use lights to indicate that power is applied to the equipment. Some use additional lights to denote whether the equipment is in full operation or on standby. Aircraft consoles use trouble lights to designate malfunctioning circuits or components. Computers use lights as readout devices for some purposes.

Indicator lights may be coded as to color, sequence, or position. They may also be controllable as to intensity. They may be stationary or rotating.

Rotary Counters

Rotary counters, as used in this discussion, are similar to the odometer (mileage indicator) on automobiles. In avionics applications, their most common usages include the following:

1. Distance and/or direction indicators in navigation systems.
2. Computer readout devices.
3. Frequency channel indicators in communications equipment.
4. Elapsed time indicators.
5. Specific occurrence counters.

Direct Angular Displacement

Direct angular displacement devices are also usually analog devices. This class of indicators includes the conventional current-operated meters, altimeters, compasses, etc., as well as the dials used to indicate switch positions, etc.

Linear Displacement

Linear displacement mechanisms, although not commonly used as final indications in avionics work, are frequently used as input devices. These devices are usually analog devices, rather than direct-reading indicators. The linear displacement of a moving part of the device is proportional to some quantity to be measured. The final indicating device is usually driven through a converter and some type of servosystem.

Remote Angular Displacement

Remote angular displacement indicating devices are those which are driven through a synchro system which is, in turn, driven by a direct angular displacement device.

Multipurpose Indicators

The avionic installations of modern aircraft have become extremely complex. Space and weight factors prohibit the use of single-purpose devices to provide each required indication. Multipurpose instruments are becoming increasingly common in aircraft, and may be broadly classified into three types.

One type of multipurpose indicator uses a single indicating mechanism for all indications. The circuit connections are switched so that any one of the various quantities may be indicated. This type is used in multimeters, radar systems, navigation equipment, etc. The quantities to be indicated must be converted into the same form in the associated circuitry prior to application to the instrument.

A second type of multipurpose instrument can provide several indications simultaneously on a single instrument. This type uses angular displacement, with all pointers using a common axis of rotation. Each pointer is driven by its own mechanism through concentric shafts.

The third type of multipurpose instrument consists of a completely separate mechanism for each indication, with all mechanisms enclosed within a single housing. The individual mechanisms may be of the same or of different basic types. Two actual instruments falling in this class are the bearing-distance-heading indicator (BDHI) and the horizontal situation indicators (HSI) discussed in the following paragraphs.

In the horizontal situation indicator (HSI) the lubber line and aircraft symbol (fig. 11-13) are fixed in position and are used as basic references for all angular indications. The command heading marker may be positioned manually by the heading set knob, or it may be automatically positioned during computer navigation mode of operation. Indicator lights behind the various mode words are used to indicate the mode of operation of the navigation system, and to designate which equipment is selected for positional and bearing reference.

The compass card, bearing pointer, command heading marker, and course pointer revolve around a common axis. The course deviation bar revolves around a central point; movement may thus appear as both linear and angular displacement.

The to-from pointer is a two-position indicator used with TACAN, as described in chapter 17 of this manual. The course set knob is used to position the course pointer.

The instrument also includes counters to indicate course and distance to a TACAN station or to a selected point. Bearing, without distance, may also be indicated to a navigation station or any UHF station under proper operating mode selections.

MICROWAVE COMPONENTS

As discussed in chapter 9 of this manual, the effects of stray and distributed capacitance and inductance increase as the operating frequency is raised. Chapter 10, in the discussion of transmission lines, presents an example of how the distributed properties are used. The

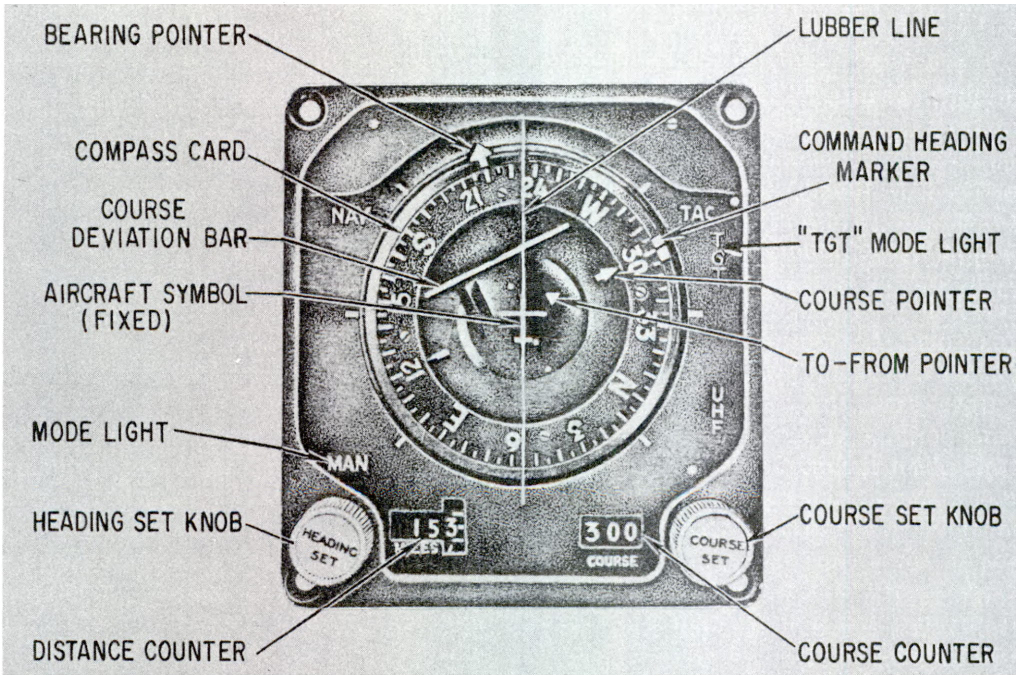

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Figure 11-13.–Horizontal situation indicator.

present discussion shows how the properties are used in components developed for use in microwave applications. It also includes a brief discussion of the ferrites used in microwave systems.

WAVEGUIDES

Basically, the waveguide is a special class of transmission line. The development of the waveguide from the two-wire transmission line (which was discussed in chapter 10 of this manual) is illustrated in figure 11-14. In a two-wire line, a quarter-wave section at the signal frequency presents a highly resistive impedance. Thus, a quarter-wave shorted stub may be used as an efficient insulator. If the stub offers adequate mechanical strength, it may be used to support the line while insulating it.

A rigid quarter-wave stub connected between the leads of a two-wire open transmission line (as shown in (A) of fig. 11-14) provides a starting point from which to discuss the development of a waveguide. In this type transmission line, efficient operation is limited to a single frequency. For all other frequencies, the insulating properties of the stub are decreased. A given stub represents a quarter wavelength at only one frequency (usually called the resonant frequency). At signal frequencies higher than resonance, the stub appears longer than a quarter wavelength, and presents an inductive impedance. At frequencies below resonance, the stub appears shorter than a quarter wavelength and offers a capacitive impedance. The greater the difference between the signal frequency and the resonant frequency of the stub, the smaller the total impedance offered by the stub. Since the stub normally has a very high Q, the effective useful range of frequencies is critical.

A metallic quarter-wave stub insulator may be placed at any point along a two-wire line. Use of several such stubs placed at convenient points along the line (as shown in (B)) improves the mechanical support of the line. Whether the stubs are used to support from above or below the line makes no difference.

If the stubs are connected together, the conductivity of the line is improved. Figure 11-14 (C) shows adjacent stubs connected by a switch. When the switch is open, each stub is excited

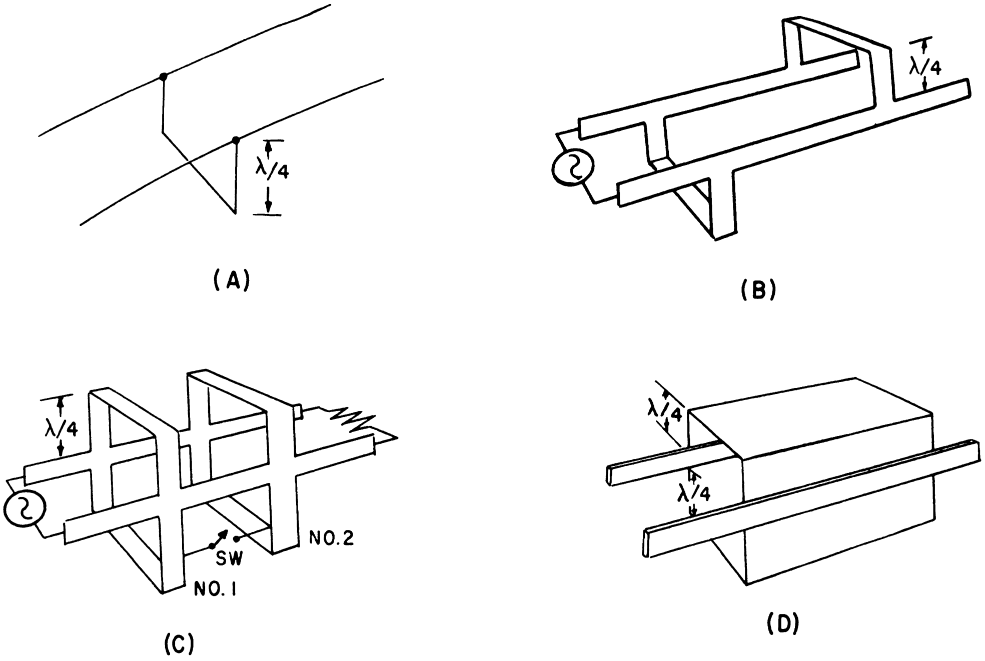

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Figure 11-14.—Development of a waveguide.

separately by the signal in the main line. Standing waves are present on the line. Stub No. 1 is excited first, No. 2 at some time later. When the switch is closed, however, the No. 2 stub is excited partially by the signal on the main line, and partially by the No. 1 stub (through the switch). If the switch is connected to corresponding points on the two stubs, the relative phase relationship of the signal at the connections is the same. Thus, the No. 2 stub requires less excitation energy; the parallel paths offer less resistance (and therefore less copper loss) and energy transfer is more efficient.

Increasing the number of stubs increases the operating efficiency. A hollow rectangular tube effectively represents a parallel line with an infinite number of stubs. Given the proper dimensions, this device becomes a highly efficient transmission line. In the waveguide shown in figure 11-14 (D), successive "stubs" are in physical and electrical contacts with each other. This effectively connects corresponding points together, and automatically provides for proper phasing.

Dimensions

As discussed previously, the stub length in open two-wire transmission lines is quite critical. In waveguides, however, the dimensions are somewhat less restricted. Figure 11-15 indicates the main dimensions of rectangular waveguides.

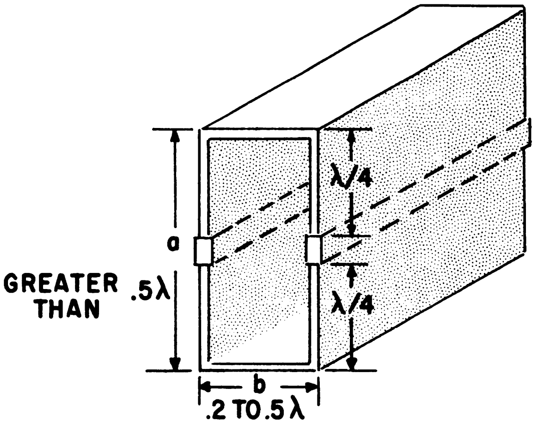

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Figure 11-15.–Dimensions in rectangular waveguides.

The waveguide shown in figure 11-15 is operating at a frequency which is the approximate minimum usable frequency. At this frequency, the waveguide is effectively a two-wire transmission line with an infinite number of shorted stubs (indicated by dashed lines in the figure). At any signal frequency higher than the one illustrated, the width of the two leads of the effective line is increased, and the remaining portion of the stub then represents a quarter wavelength. At frequencies lower than the one illustrated, however, the stubs are less than a quarter wave and the leads are not adequately insulated. Thus it may be assumed that the (a) dimension of the waveguide is not critical, except that the signal must be at least a certain minimum frequency.

In open transmission lines, the spacing of the lines is critical only with respect to voltage breakdown. If the wires are placed too close together, arcing can occur, and energy losses become excessive. The same principle applies to the (b) dimensions of the waveguide.

The main limitation on the length of either the open line or the waveguide is the energy losses incurred by the signal in transit through the device from one end to the other.

The frequency at which the quarter-wave stub sections appear to meet and cease to exist is called the CUTOFF FREQUENCY, and the corresponding wavelength is called the CUTOFF WAVELENGTH. Thus the analogy provides a basis for the formula $\lambda_{co} = 2a$ (given in Basic Electronics). In this formula, λ_{co} is the wavelength at the cutoff frequency of the waveguide, and (a) is the wide dimension as indicated in figure 11-15. In practical waveguides, the (b) dimension is normally between 0.2 and 0.5 wavelength at the cutoff frequency.

Energy in Waveguides

Energy is transferred within the waveguide by electromagnetic fields; currents and voltages merely aid in establishing these fields. In understanding the operation of waveguides, it is important to know when a good current path is required and where the voltage must be high. It is also important to know where strong fields will exist and to understand the composition of the fields. It is normally by means of fields that energy is introduced into or removed from the waveguide. The operation of the waveguide involves two field components—the electric field and the magnetic field.

ELECTRIC FIELD.—As discussed in Basic Electricity, the existence of an electric field indicates that a difference of potential exists between two points. An excited transmission line has a standing wave of voltage along its path; part of the line is positive, part is negative. An instantaneous field is set up between the wires. The standing wave, and therefore the electric field, varies in magnitude (intensity) progressively along the line. Since the exciting voltage varies at a sine wave rate, the electric field also varies sinusoidally.

The electric field, as it exists in a waveguide, is shown in figure 11-16 (A). This is an instantaneous representation of the field at its peak. Over a period of time (during each cycle), the field decreases to zero, reverses polarity and builds up to another maximum, decreases to zero, then reverses and expands again. Successive zero points occur at half-wave intervals along the length of the line; successive maxima, alternating in polarity, also occur at half-wave intervals.

NOTE: In illustrating the direction of the fields, standard practice is to use dots (•) and crosses (x). The (•) inducates that the direction of the field is toward the observer; the (x) indicates that the field is away from the observer.

Note that the lines of force which make up the electric field (called the E-lines) exist between the (b) dimension walls, and are perpendicular to the wide (a) dimension walls. Also note that the field has maximum intensity halfway between the (b) dimension walls, decreasing toward zero as it nears the wall. (The importance of this characteristic is covered later in this discussion.)

MAGNETIC FIELD.—Any expanding and collapsing electric field creates an alternating magnetic field. A visual representation of the sinusoidal magnetic field at an instantaneous maximum point is shown in figure 11-16 (B). Note that the field forms closed loops approximately half a wavelength long, with successive loops reversed in polarity. Note also that the magnetic lines (called H-lines) are parallel to the walls of the waveguides.

The magnetic field is strongest at the edges of the waveguide and weakest at the center of each loop (where the standing wave of current is zero at all times).

COMPOSITE FIELD.—Electromagnetic waves are made up of electric and magnetic field components. Energy travels down the waveguide in the form of wavefronts.

As the wavefront progresses down a waveguide, it interacts with a wavefront reflected from the other end. This interaction results in standing waves (similar to the standing waves of current and voltage in transmission lines). It is in these standing waves that the energy exists within the waveguide. Figure 11-16 (C) illustrates the composite electromagnetic standing waves in a section of waveguide.

In the figure, note that the electric and magnetic components of the composite field are oriented mutually perpendicular to each other and to the direction of propagation. Also note that the points of maximum electric and magnetic field intensity coincide, as do the points of minimum field strength. Propagation of energy in waveguides differs in some respects from that in free space.

In free-space propagation, the transmitted wave expands in an everwidening circle. In waveguides, it is confined within the conductive walls, and no electromagnetic field exists outside the waveguide. Instead, as the wave travels down the guide, it strikes the walls at an angle and is reflected at an equal angle. If energy propagation is to be sustained within the waveguide, two major "boundary" conditions must be fulfilled.

BOUNDARY CONDITIONS.—The first boundary condition that must be met is that there must be no component of the electric field tangent to the walls of the waveguide. An electric field is equivalent to a voltage; when impressed across a perfect conductor (the walls of a waveguide), it is decreased effectively to zero. Thus the parallel component of the E-field diminishes to zero as it approaches the walls. The remaining component of the E-field is perpendicular to the walls in the (a) dimension.

The second boundary condition concerns the magnetic field. No component of the magnetic field can exist perpendicular to the inner surface of the waveguides. Since the electric and magnetic components of the composite field are mutually perpendicular, satisfaction of one boundary condition usually guarantees satisfaction of the other also.

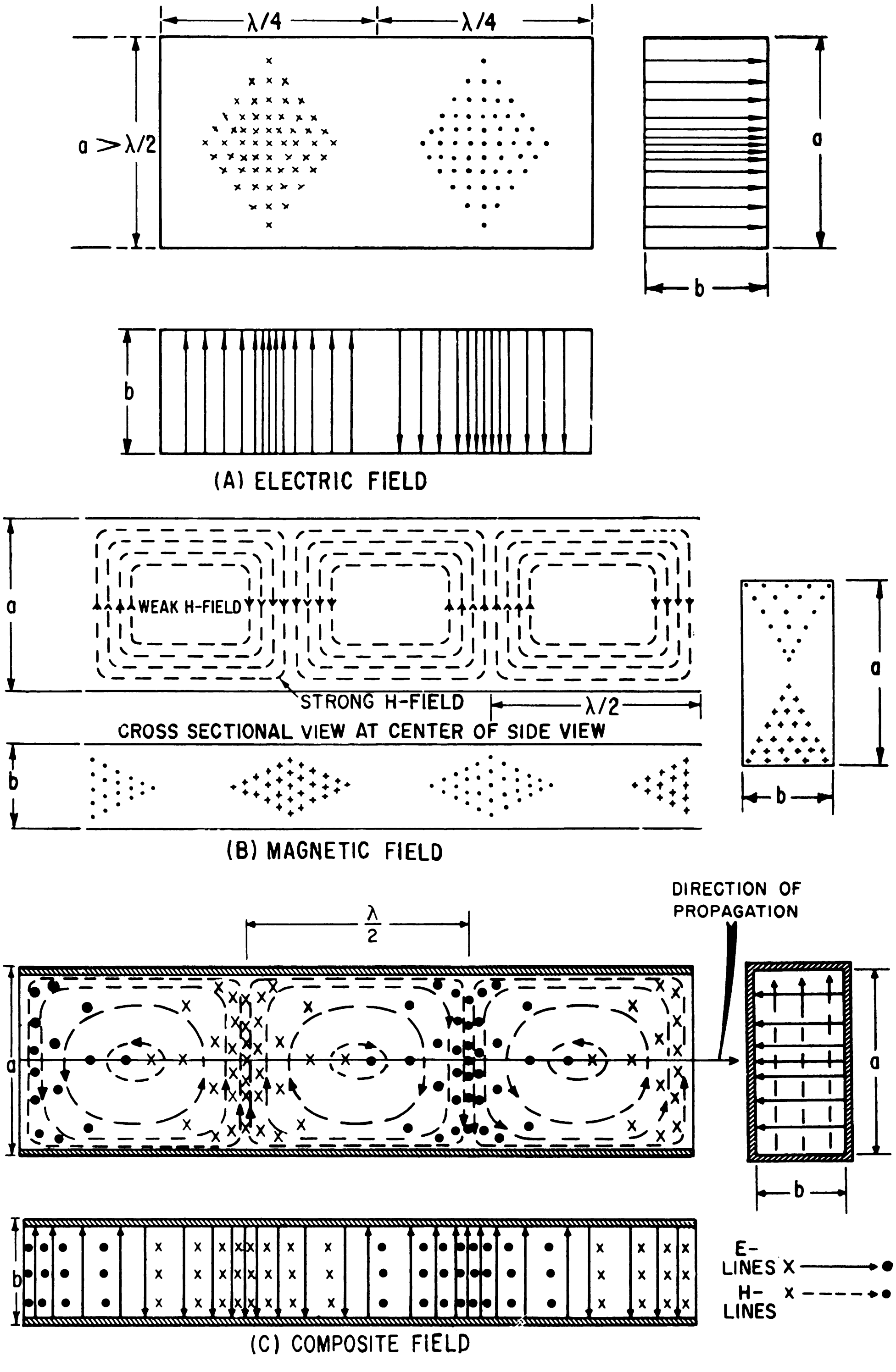

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Figure 11-16.–Fields in waveguides. (A) Electric; (B) magnetic; (C) composite electromagnetic.

Circular Waveguides

Waveguides have been developed which have a circular cross section as well as those having a rectangular cross section. Although in less common usage than rectangular, circular waveguides have characteristics which make them particularly useful in some applications. In general, the development of the circular waveguide may be explained in the same manner as that of the rectangular.

The two conductors represented by the dashed lines in figure 11-17 are assumed to be part of the waveguide wall. The remaining part of the wall represents the quarter-wave stub section which act as the insulators.

The cutoff wavelength of the circular waveguide is 1.71 times the diameter of the guide. The diameter must be 1.17 (2/1.71) times the (a) dimension of a rectangular waveguide having the same cutoff frequency.

Modes in Waveguides

As mentioned previously, at frequencies higher than cutoff, the wide dimension of the waveguide becomes increasingly greater than a half wavelength. At a frequency twice that of cutoff, this dimension is a full wavelength, with each stub then representing a half-wave section. If the waveguide and its fields are to fulfill the boundary conditions required for propagation, the field configuration must be quite different from that previously indicated. In other words, the waveguide must assume a different mode of operation.

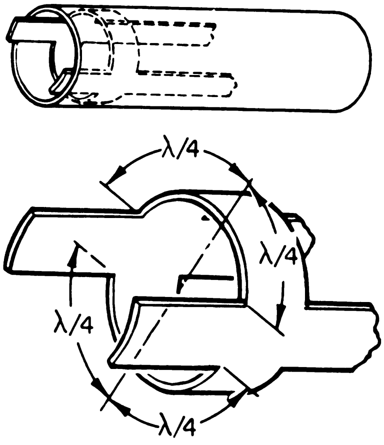

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Figure 11-17.—Circular waveguide.

The normal configuration of the electromagnetic field in a given waveguide is called the DOMINANT MODE OF OPERATION of that waveguide. Other modes are also possible in any waveguide, and some of these modes are used in radar applications.

Any field configuration can be classed as either a TRANSVERSE ELECTRIC MODE or as a TRANSVERSE MAGNETIC MODE (abbreviated TE or TM, respectively). In a TE mode, all parts of the electric field are transverse (perpendicular to the length of the waveguide) and no E-lines are sustained parallel to the direction of propagation. In a TM mode, the plane of the H-field is transverse and no H-lines are parallel to the direction of propagation.

A wavefront in free space is a TEM mode, since both fields are perpendicular to the direction of propagation. Due to the boundary conditions, however, this mode cannot exist in a waveguide. Under any set of operating conditions, one field in any waveguide will be predominantly transverse—this field determines the basic classification of the mode as TE or TM. To complete the description of the field pattern, two subscript numbers are used following the TE or TM.

In rectangular waveguides, the field is described in relation to the wide and narrow dimensions. The first subscript indicates the number of half-wave patterns of the transverse field across the wide dimension. The second subscript indicates the number of half-wave patterns of the transverse field across the narrow dimension. Both measurements are made across the center of the cross section.

In circular waveguides, the field is described in relation to the circumference and diameter. The first subscript indicates the number of full-wave patterns of the transverse field around the circumference of the waveguide. The second subscript indicates the half-wave patterns occurring across the diameter.

Figure 11-18 illustrates several modes which occur in waveguide operation. The dominant mode for rectangular waveguides is shown in (C), and the dominant mode for circular waveguides is shown in (F).

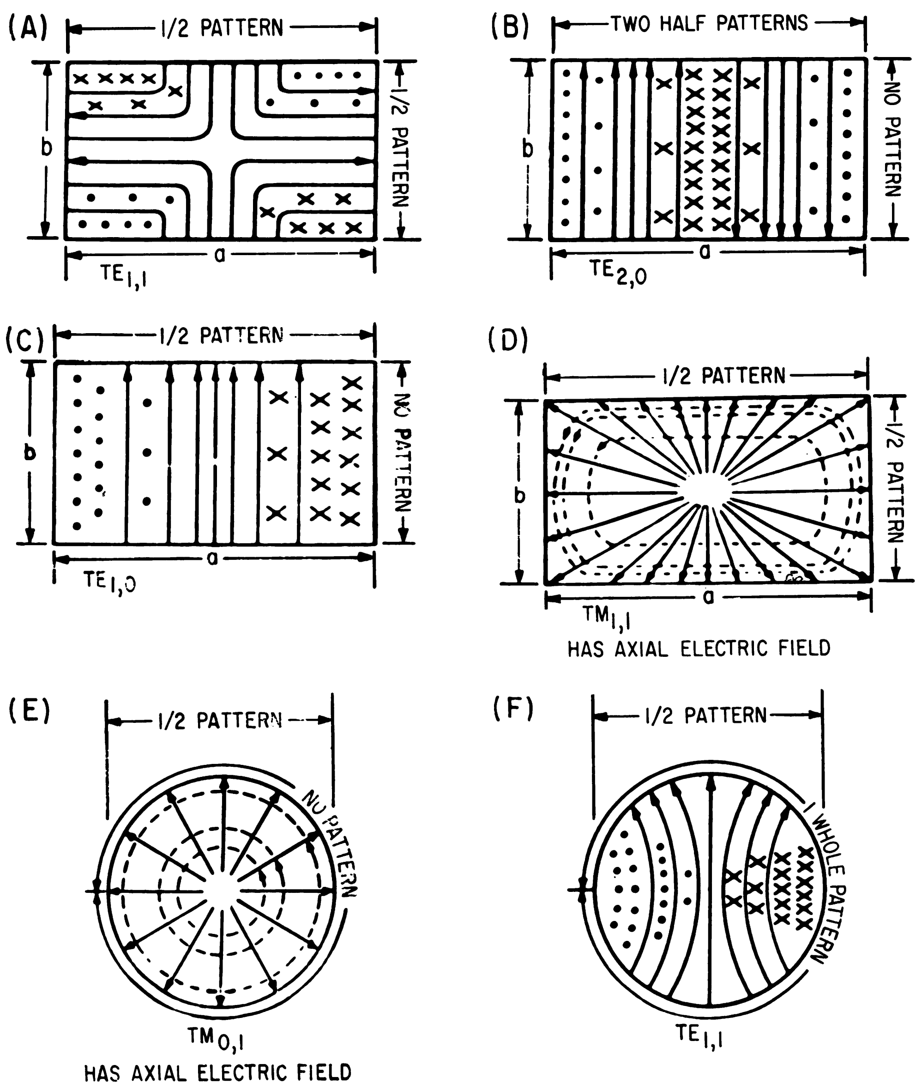

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Figure 11-18.–Modes and field configurations in waveguides.

Note in (D) and (E) that the electric field is axial; therefore the magnetic field is transverse and the modes are designated TM.

Excitation of Waveguides

As with any transmission line, the waveguide must be properly excited in order to carry the energy from one point to another. Waveguides, however, do not have the two convenient connection points possessed by the conventional RF line. In waveguides, the energy is in the form of an electromagnetic wave; therefore the excitation device must cause these fields to be created within the guide. Excitation may be in either of three principal forms–electric fields, magnetic fields, or electromagnetic fields.

ELECTRIC FIELD.–Inserting a small probe or antenna into a waveguide and applying an RF signal causes current to flow in the probe. This current sets up an electrostatic field; E-lines detach themselves from the probe and propagate in the waveguide. The propagating E-lines establish corresponding H-lines and result in the formation of a composite electromagnetic field within the waveguide. If the probe is positioned in the proper location and supplied the proper signal for a specific waveguide mode, a field having considerable intensity may be established and sustained.

Figure 11-19 (A) illustrates the excitation of a waveguide by means of an electric field.

The best place to locate the probe is in the center of the wide dimension, parallel to the narrow dimension, and one-quarter wavelength away from the shorted end of the guide, as shown (the field is strongest at the quarter-wave point). This is the point of maximum coupling between the probe and the field.

The probe will work equally well at any point where E-lines exist with maximum intensity (for example, a three-quarter wavelength distance from the shorted end).

Usually the probe is fed with a coaxial cable. This cable is kept short to derive greatest benefit from the waveguide. Impedance matching between the cable and the waveguide is accomplished by varying the distance of the probe from the end of the waveguide (by moving the shorted end) or by varying the length of the probe. Any mismatch will cause unwanted reflections within the waveguide.

The degree of excitation can be reduced by reducing the length of the probe, moving it out from the center of the E-field, or shielding it. Where it will be necessary to vary the degree of excitation frequently, the probe is made retractable, and the end of the waveguide is fitted with a movable plunger.

In pulse-modulated radar systems there are wide sidebands on both sides of the carrier. In order that a probe feed system does not discriminate too sharply against frequencies which vary from the carrier frequencies, WIDEBAND probes are often used. A wideband probe is large in diameter and is conical or doorknob in shape. A conical probe is capable of handling moderate amounts of power, but for the high power sets, doorknob probes are used. The same types of probes are used to take energy out of waveguides and deliver it to coaxial cables.

MAGNETIC FIELD.–Another way of exciting a waveguide is by setting up a magnetic H-field in the waveguide. This can be accomplished by placing a small loop which carries a high current in the waveguide. A magnetic field builds up and expands until it fills the space within the waveguide. If the frequency of the current is correct, energy will be transferred from the loop to the waveguide. A loop for transferring energy into a guide is shown in figure 11-19 (B). Notice that the loop is fed by a coaxial cable. The location of the loop for optimum coupling to the guide is at the place where the magnetic field, which is to be set up, is of greatest strength.

When less coupling is desired, the loop may be rotated or repositioned until it encircles a smaller number of lines of force.

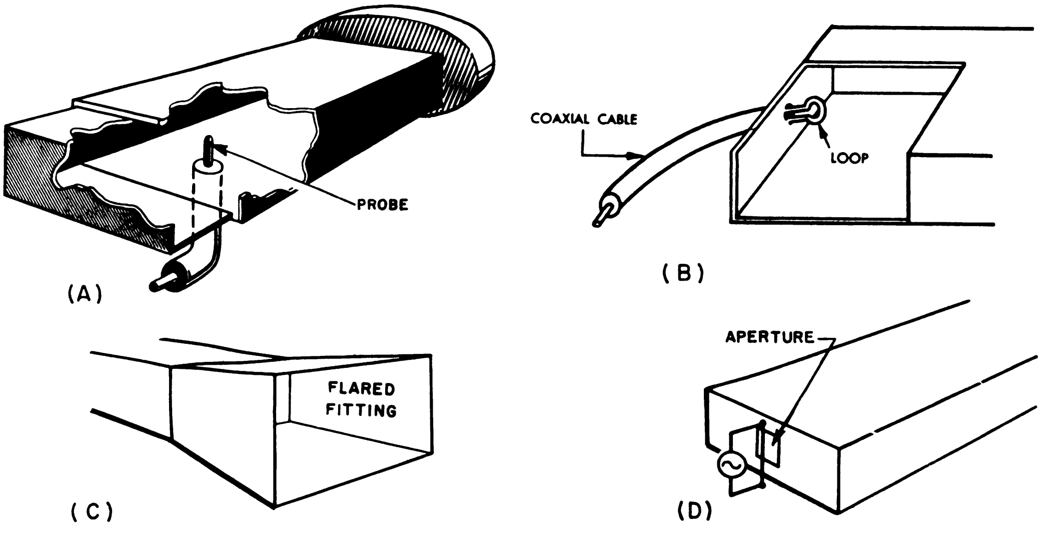

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Figure 11-19.–Exciting a waveguide.

When an excitation loop is used in radar equipment, its proper location is often predetermined and fixed either during construction or final tuning at the factory. In test or laboratory equipment, the loop is often made adjustable.

When a loop is introduced in a guide at a point where an H-field is present, a current will be induced in the loop itself. Thus, the loop may take energy out of the waveguide as well as put energy into it.

ELECTROMAGNETIC FIELD.—It might seem that a good way to excite the waveguide or to couple energy out of it is simply to leave the end open. However, this is not the case; when energy leaves a guide, fields exist around the end which result in mismatch. In other words, reflections and standing waves would result if the end were left open. Thus, simply leaving the end open is not an efficient way of letting energy out of the waveguide.

In order for energy to move smoothly into or out of a guide, the opening of the guide may be flared like a funnel. This makes the guide similar to a V–type antenna. This method, shown in (C) is called a horn and in effect eliminates reflection by matching the impedance of free space to the impedance of the waveguide. When the mouth of the horn is exposed to electromagnetic fields, they enter and are gradually shaped to fit the waveguide. The horn is directional in characteristic. It sends or receives the greatest amount of energy in front of the opening.

Another method for either putting energy into or removing it from waveguides is through slots or openings. This method is sometimes used when very loose coupling is desired. In this method (fig. 11-19 (D)), energy enters the guide through a small aperture. Any device which will generate an E-field may be placed near the aperture, and the E-field will expand into the waveguide. A single wire is shown; on it, E-lines are set up parallel to the wire due to the voltage difference between parts of the wire. The E-lines expand first across the aperture, then across the interior of the waveguide. If the frequency is correct and the size of the aperture properly proportioned, energy will be transferred to the waveguide with a minimum of reflections.

EXTRACTION OF ENERGY.—In waveguides, as with many other electrical networks, reciprocity exists in the excitation system. Reciprocity means that energy may be either introduced into the waveguide or removed from the waveguide, using the same coupling devices and methods, with the same efficiency of transfer.

RESONANT CAVITIES

By the simple expedient of closing the ends of a waveguide to form an enclosure, a cavity is formed. If this cavity is then excited in a proper manner by the proper frequency, it will resonate. The resonant frequency of the cavity is determined by the dimensions, which are somewhat more critical than those of a waveguide.

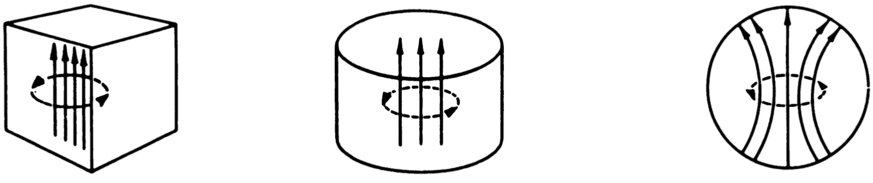
In order to resonate, the cavity makes use of the distributed inductance and capacitance of the enclosing box. This limits the practical use of resonant cavities to microwave frequencies. However, at microwave frequencies, resonant cavities normally possess value of Q considerably in excess of any value obtainable with lumped components at lower frequencies.

Fields in Resonant Cavities

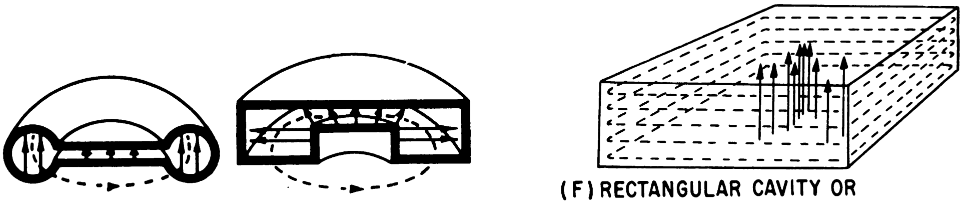
As in the waveguide, operation of the resonant cavity is best described in terms of the fields rather than in terms of currents and voltages. Cavities may have various physical shapes. A chamber enclosed within conductive walls may resonate at any of several frequencies and thus produce a number of field configurations, depending on the size and shape of the chamber. As in waveguides, these field configurations are called modes. Figure 11-20 illustrates several shapes of cavities and the dominant mode of each.

Of the types shown in the figure, the cylindrical type cavity (B) is useful in wavemeters or other frequency measuring devices. The cylindrical ring (E) and doughnut (D) are used in many microwave oscillators as the frequency-determining element. The waveguide section (F) is used in some radar systems as a mixing chamber for combining signals from two sources. The cube (A) is a special type of waveguide section. The sphere (C), although not in common usage, may be used for mixing multiple inputs, for extracting multiple outputs, for changing the mode of operation, or for impedance matching.

Note that in each type cavity shown, the voltage is represented by E-lines between the top and



(A) CUBE $TE_{1,0,1}$ (B) CYLINDER $TM_{0,1,0}$ (C) SPHERE $TM_{0,1,1}$



(D) DOUGHNUT-SHAPED $TM_{0,1,0}$ (E) CYLINDRICAL RING $TM_{0,1,1}$ (F) RECTANGULAR CAVITY OR (HALF-WAVELENGTH SECTION OF WAVEGUIDE) $TE_{1,0,1}$

AT.201

Figure 11-20.–Fields in resonant cavities.

bottom of the cavity. The current, due to skin effect, flows in a thin layer on the surface of the cavity. The H-field is strong where the current is high; the strongest H-field is at the vertical walls of the cavity, and diminishes toward the center where the current is zero. This characteristic results from the presence of standing waves, similar to the action on a quarter-wave section of transmission line or waveguide. The E-field is maximum at the center and decreases to zero at the edge where the vertical wall is a short circuit to the voltage.

The modes in a cavity are identified by the same numbering system that is used with waveguides, except that a third subscript is used to indicate the number of patterns of the transverse field along the axis of the cavity (perpendicular to the transverse field). For example, the cylindrical cavity shown in (B) is a form of circular waveguide. The axis is the center of the circle. The transverse field is the magnetic field; therefore, it is TM (transverse magnetic). Around the circumference there is a constant magnetic field. (The H-lines are parallel to the circumference.) Therefore, the first subscript is 0. The distance across the diameter is one-half wave; thus the second subscript is 1. Through the center, along the axis, the H-field strength is a constant zero; this makes the third subscript 0. The complete description of the mode is $TM_{0,\ 1,\ 0}$.

When a section of waveguide is closed on both ends in the form of a rectangular cavity, shown in (F) of figure 11-20, standing waves are set up and resonance occurs. The simple mode in this cavity is the same as the dominant mode of a rectangular waveguide; that is, it is $TE_{1,\ 0}$. The third subscript of the mode, which is determined by a plane perpendicular to the E-field, is 1. Thus the complete description of the simple mode in the rectangular cavity is $TE_{1,\ 0,\ 1}$ (transverse electric).

Exciting the Cavity

A cavity resonator may be excited in any of three predominant methods. These methods are illustrated in figure 11-21.

The first method (A) is by inserting a probe into the cavity. The voltage applied to the probe sets up an E-field with the E-lines parallel to the probe. As the E-field expands, it in turn sets up an H-field. These fields expand and collapse; the wavefronts travel through the cavity and are reflected from the end. If the physical dimensions are correct, these wavefronts will return at the proper time to reinforce the original fields and produce standing waves. Due to

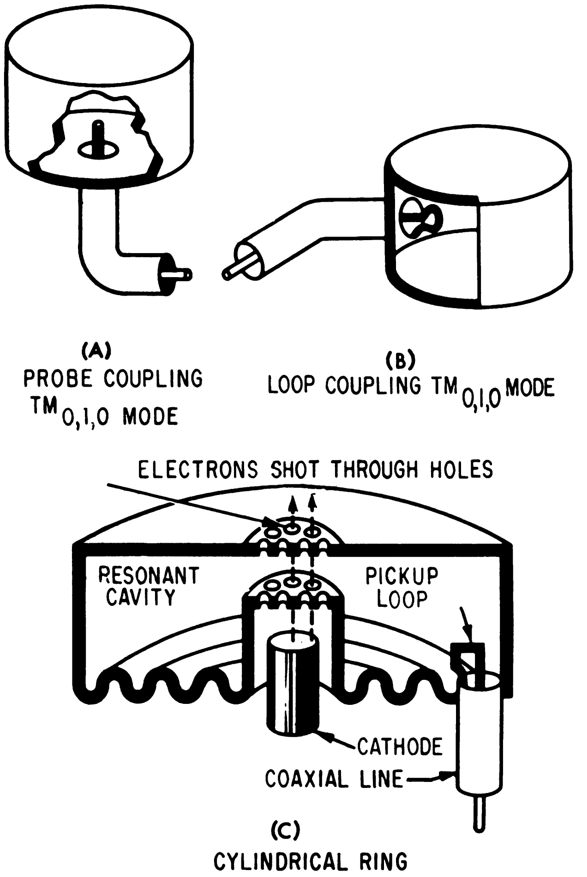


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Figure 11-21.–Exciting the cavity.

the high Q of the cavity, these oscillations will sustain themselves for an appreciable time, thus requiring only occasional excitation.

Another method (B) uses a magnetic loop. The loop is placed in a region where the magnetic field will be located. The currents in the loop set up an H-field within the cavity. The expanding and collapsing of the fields and the reflection of the wavefronts combine to maintain each other (if the size of the cavity is correct).

Either of the above methods may also be used to remove energy from the cavity.

A third method (C) is used with a cylindrical ring type cavity. The energy is placed into the cavity by clouds of electrons, which are virtually "shot" through the holes in the center of a perforated plate. As each cloud passes through, it creates a disturbance in the space inside the cavity until a field is set up. It may be said that the cloud of electrons produces a voltage difference between the perforated plates, and thus sets up an E-field.

Tuning the Cavity

Three methods for adjusting the resonant frequency in a cavity are shown in figure 11-22. One method uses a cylindrical cavity with an adjustable disk. When a $TE_{0,1,1}$ mode is used, the size of the cylinder may be changed along the axis to change the resonant frequency. The smaller the volume of the cavity, the higher the resonant frequency. The movement of the disk may be calibrated in terms of frequency. Usually in the case of high frequency equipment, a micrometer adjustment is used to change the position of the disk.

A second method of tuning the cavity employs threaded plugs which are inserted in the side of the cavity. The plug reduces the length of the magnetic field in the cavity in a manner similar to reducing the inductance of the tuned circuit.

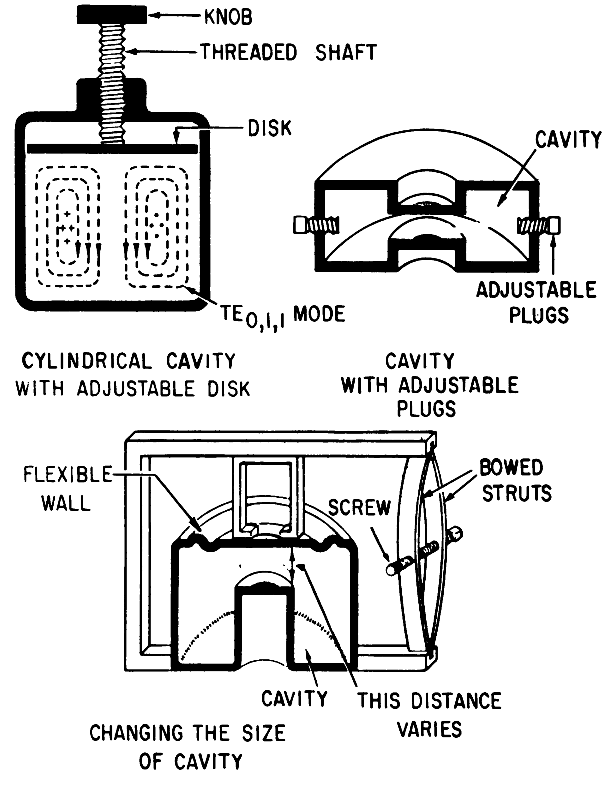

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Figure 11-22.–Tuning the cavity.

The deeper the plug extends into the cavity, the higher the frequency.

In the third method, the interior of the cavity, which is part of the interior of a vacuum tube, is sealed and evacuated. In this method a frequency change occurs whenever the top and the bottom of the cavity are moved away from (or toward) each other. This is accomplished by turning a screw which passes through two bowed struts. As the distance varies, the volume and the capacitance between the top and bottom of the cavity are changed. As the change in capacitance is the chief result of the change in the distance between the plates, the resonant frequency is proportional to the distance from the top to the bottom.

Another way of changing the frequency (not shown) is by changing the method of exciting the circuit. This can be done by making the exciting element either capacitive or inductive. (This can occur either accidentally due to improperly tuned circuits or deliberately as a means of tuning the cavity.)

MAGNETRONS

A magnetron is used as the transmitting tube in most pulsed transmitters operating at frequencies above 1,000 MHz. The fact that transit time has little influence on the magnetron, whereas it is a limiting factor in the operation of conventional tubes, makes this type tube desirable for microwave pulsed operation. Several other types of oscillators have been developed to compete with magnetrons as radar high power oscillators. In addition, there are some velocity modulated tubes (such as the klystron) which operate in the radar range and are capable of greater power output than the triodes. Klystrons are discussed later in this chapter.

The magnetron, which is a self-excited oscillator, possesses rather poor frequency stability when compared with the most stable lower frequency oscillators (electron coupled or crystal controlled). However, the overall system does provide adequate stability when AFC is used with the local oscillator.

As explained in Basic Electronics, the magnetron is a type of diode having an axial magnetic field perpendicular to the electric field between its cathode and anode. The magnetic field could be produced by an electromagnet but is usually provided by a permanent magnet.

The tube consists of a cylindrical plate, with a cathode positioned coaxially inside it. The tuned circuits in which the oscillations take place are resonant cavities within the plate structure.

Theory of Operation

The theory of operation of a magnetron is based on the effects of electric and magnetic fields upon electrons moving within the fields. These effects are as follows:

1. Within an electric field, a moving electron is subjected to a force proportional to the strength of the field and in a direction opposite to it.
2. Within a magnetic field, the force exerted is in a direction mutually perpendicular to both the field and the direction of electron movement.
3. Within mutually perpendicular electric and magnetic fields, the path of the electrons is determined initially by the velocity of the electron, and is then modified by the individual and combined effects of the two fields.

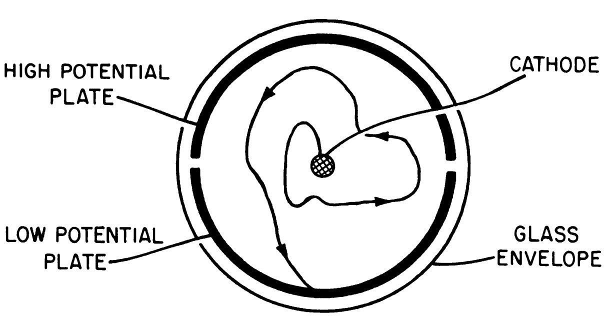
The fundamentals of magnetron action, using a permanent magnet and a pulsed d-c electrostatic field, are explained in Basic Electronics, NavPers 10087-B. An important conclusion, which results from the fundamental observations found in Basic Electronics, is summarized in the following paragraph.

For a fixed applied d-c potential, the radius of curvature of the electron path is determined by the strength of the magnetic field. By increasing the d-c potential, however, the velocity of the electron is increased and the magnetic field has a greater effect on the electron path, decreasing its radius. Thus the path of the electron can be altered by changing the strength of either the electric field or the magnetic field. The strength of these fields is critical, because they determine the path of the electrons, thus determining the efficiency of the tube.

GENERATION OF A. C.–In order to produce an a-c voltage in a magnetron, a split (or segmented) anode and a strong axial H-field are required; a high d-c potential is then applied to all anode segments. (The anode must be split into an even number of segments, and the cathode preheated to emit electrons.) As soon as the d-c voltage and the magnetic fields are applied, oscillations build up and the segments become alternately positive and negative. The a-c power is generated by transferring a portion of the d-c power (consumed in the circuit) into a-c energy (in the oscillations) as described below.

The applied d-c voltage accelerates the electron, which starts to move toward the anode segment having the higher positive potential at that instant. The energy of the applied d. c. is thus transferred to the electron as kinetic energy. Strong magnetic fields force the electron to follow a sharply bent spiral path. As the field reverses, the electron is slowed down (due to a decrease in the accelerating force of the d-c field) and transfers some of its kinetic energy to the a-c field of oscillation. The electron may spiral several times before reaching the anode, thus giving up most of its energy to the alternating field. (See fig. 11-23.)

In this magnetron, the frequency of oscillation is determined by the transit time of the electrons, and is quite unstable. Electrons arriving at the anode segments a little early tend to increase the frequency, while those arriving late tend to decrease it. In order to provide better stability, resonant circuits are introduced between adjacent anode segments, or between each anode segment and the cathode. The frequency of oscillation is then determined by the resonant frequency of these circuits. Since the stability of the circuit can be improved by using a higher Q resonant circuit, the use of resonant cavities is standard at those frequencies high enough to make this practical.



AT.204

Figure 11-23.–Split anode magnetron.

The RF fields in the cavities may or may not be in phase. The phase relationship is determined mainly by the applied voltage and the strength of the magnetic field, but some improvement in the phasing may be realized due to the coupling between the cavities. The desired coupling may be obtained by connecting selected segments together. This procedure is known as STRAPPING, and is covered in more detail in a later discussion.

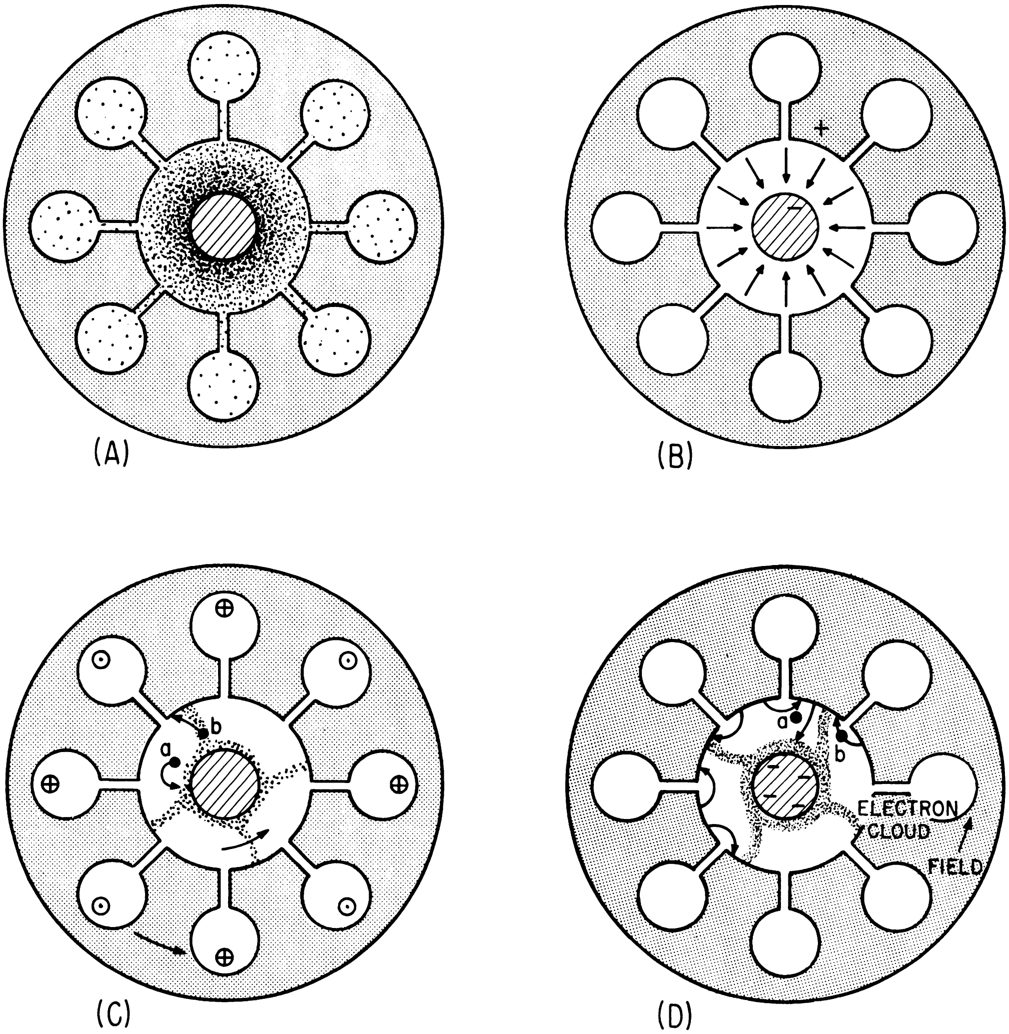
The multicavity magnetron requires an even number of anode sections (usually eight or more) situated around a cylindrical chamber (called the INTERACTION SPACE) with the cathode coaxially centered inside it. A resonant cavity is located between each pair of anode segments, and may be connected to the interaction space by a narrow slot. (See fig. 11-24.)

The body of the magnetron and the anodes are at d-c ground potential, and a highly negative d-c potential is applied to the cathode. The resonant frequency is determined by the physical dimensions of the cavities. Due to the oscillations, high frequency potentials are imparted to the anode segments.

If each cavity is at a 180° phase relation with its neighbors, adjacent anode segments have opposite polarities at any given time. An oscillating E-field exists between each pair of segments in the path of the electrons. Strength of the magnetic field is relatively fixed; therefore the voltage applied to the cathode must be adjusted so that the majority of the electrons move against these oscillating fields and surrender most of their energy to the RF field, thus helping to sustain oscillation.

ELECTRON SPACE CLOUD.–Electrons within the interaction space do not travel individually, nor are they evenly spaced. Rather, they tend to gather into spoke-shaped clouds. In figure 11-24 (A), the space charge is shown as it would exist in a magnetron that is not oscillating (due to the lack of a d-c potential). In (B), the application of a d-c voltage sets up the d-c electric field as shown. The arrows indicate the direction of the field (positive to negative). It must be remembered that electrons will be accelerated so that they move in a direction opposite to that of the field.

With the establishment of the d-c field, the magnetron is shocked into oscillation, and RF fields are established. These RF fields set up



AT.205

Figure 11-24.–Action of space cloud.

alternating polarities on adjacent anode segments. The alternating fields aid or oppose the d-c fields, and tend to accelerate or retard electrons in the space cloud.

Electrons being accelerated due to the addition of the two fields (such as electron "a" in (C) of figure 11-24) tend to absorb energy from the RF field. Due to their high velocity, the magnetic field has greater effect upon them, decreasing the radius of curvature and causing them to return to the cathode. They strike the cathode with high velocity, cause secondary emission, and give up their kinetic energy to the cathode in the form of heat. This is known as cathode back-heating. (Back-heating is often great enough to require a decrease or even removal of filament voltage from the magnetron as its cathode current nears its normal operating value.)

On the other hand, those electrons being retarded (electron "b" in fig. 11-24 (C)) due to opposing fields have their velocities decreased and impart energy to the RF field. Due to the decreased velocity, the radius of curvature is increased and the electron paths terminate at the anode. Sorting of electrons in the space charge tends to create spokes in the electron cloud. The spokes rotate in synchronism with the RF fields and the space cloud. Loss of sync between the clouds and the RF field tends to kill oscillation. The applied potential and the strength of the magnetic field are fairly critical, since they determine the intial velocity of the electron and vary radius of curvature during transit, respectively.

The spokes are rather narrow, with sharply defined boundaries–the result of focusing by the RF field. In (D), electrons traveling in advance of the spoke "a" are in an area where the radial components of the d-c and RF fields oppose. The velocity of the electron is decreased and the radius of curvature is increased, allowing the spoke to catch up and collect the electron. Those electrons which lag the spoke "b" are in an area of aiding fields. Their velocity is increased, the radius of curvature is decreased, and the electron catches up with the spoke and is captured. Thus, capturing of electrons tends to focus the electrons into tight spokes, and keeps the edges sharply defined.

As the spokes of the electron cloud pass an anode segment, electrons are repelled from that segment, traveling around the cavity on either side to other segments. This action creates a positive charge on the segment being passed by the cloud. As the cloud rotates to the next segment, it encounters a maximum negative polarity (due to the electrons repelled from the previous segment). It again displaces electrons as previously, causing a polarity reversal. This displacement current is the principal current of the RF oscillation. If the alternation of RF field and the rotation of the space cloud are properly synchronized, the electrons reaching the anode from the interaction space have a 90° phase relationship and do not contribute to the oscillation. Electrons passing the gap (cavity) give up part of their energy to the RF fields, sustaining oscillation.

By varying the magnetic field strength or the d-c voltage applied to the cathode, it would be possible to "kick" the anodes slightly early or slightly late, thus varying the resonant frequency. However, there is a very narrow range through which the frequency can be varied in this manner, and the magnitude of oscillation decreases very rapidly with any change of sync. Therefore, this method is not in common use.

Modes of Operation

There are various modes of a magnetron, and they are identified by the number n, which specifies the number of cycles of variation of the field quantities that occur around the circumference of a circle surrounding the cathode. For each mode of oscillation of a magnetron, like those of other cavity resonators, there is a particular pattern of field variations. In the zero mode, the fields do not enter the anode cavities and the frequency of the mode is not controlled by the cavities; thus this is an undesirable mode of operation. With the exception of the π mode, all modes are degenerative. Degenerative modes are in reality a combination of two or more modes having the same resonant frequency. In the π mode of operation, adjacent anode segments are exactly 180° (one-half cycle, or π radians) apart in phasing.

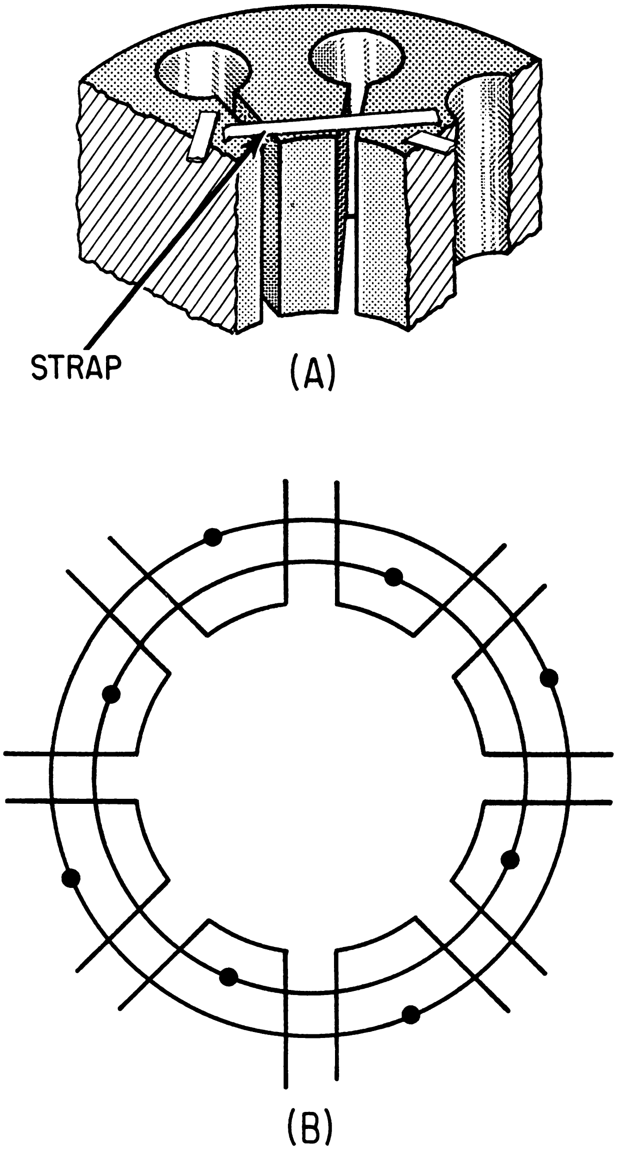
These degenerative modes are caused by very close coupling between resonators having the same frequency, allowing the mutual inductance to either add or substract from the natural inductances of the cavities.

Since a slight variation may cause a shift from one of these modes of operation to another with a resultant change in output frequency, these modes are highly undesirable. Since the π mode of operation is not degenerative, it is the preferred mode of operation.

In order to insure operation in the π mode, the procedure known as STRAPPING is used. Since in the π mode of operation adjacent segments must be operating with a 180° phase relation, then alternate segments should be in phase. In order to guarantee this in-phase condition, alternate segments are connected as shown in figure 11-25 (A).

While operating in the π mode, there is no current flow through the straps, so there is a negligible inductive effect on the cavities. On the other hand, there is a very high electric field between each strap and the anode segment to which it is not connected. This adds an effective capacitance to the associated cavity, lowering its frequency. If the adjacent segments are not phased 180° apart, the magnetron tries to oscillate in an undesirable mode; the straps are then connected to points of unequal potential, and current flows in the straps. This current makes each strap appear as an effective inductance in parallel with the cavity, increasing the frequency of this undesired mode and giving better mode separation. The potential difference between the strap and the segment decreases, presenting a lower effective capacitance to the cavity and increasing the frequency of the undersired mode even more.

NOTE: Some magnetrons make use of double ring strapping as illustrated in figure 11-25 (B).



AT.206

Figure 11-25.—Strapped magnetron. (A) Cutaway view; (B) double strap.

In addition, there are other strapping methods (not shown). All methods are used for the same purpose, but some are more effective than others.

Types of Cavities

The anode of a magnetron is usually a copper block into which resonant cavities have been cut. Several forms of these cavities are shown in figure 11-26.

The capacitance of the cavity is primarily the distributed capacitance between the anode segments forming the resonator; the inductance is distributed around the inner perimeter of the cavity. Each resonator is essentially a parallel resonant circuit, and all are connected effectively in series.

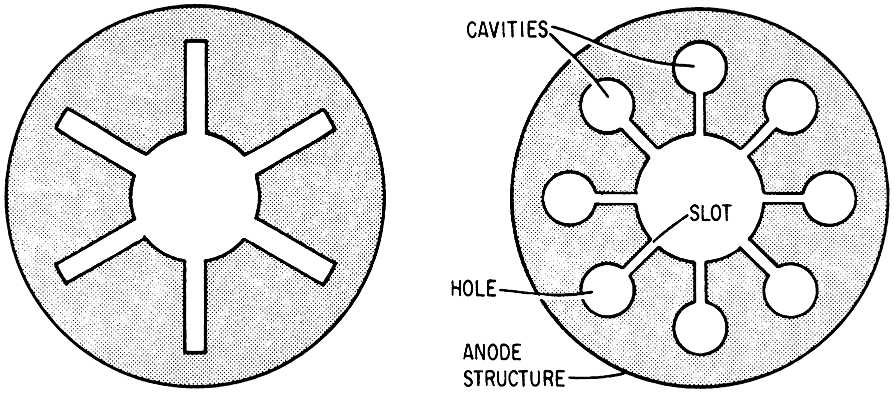
In figure 11-26, the SLOT type anode (A) is effectively a high C/L ratio, the HOLE and SLOT (B) is a medium C/L ratio, and the VANE (C) is a high L/C ratio. The RISING SUN (D) provides excellent separation at high frequencies without strapping.

In the rising sun type anode, the overall resonant frequency lies somewhere between that of the large cavities and that of the small ones. A degree of coupling exists between the cavities of the same size, and the resultant frequency differs from the extremes by an amount depending on the amount of that coupling. Optimum separation between the π mode and the low and high frequencies is obtained through anode block design.

The RF voltage across the large cavities is greater than that across the smaller ones, so the RF field is not uniform. The circulating currents in the large cavities are all in the same direction, and are greater than those in the small cavities; therefore, there is a net circulating current. By applying the proper values of voltage and magnetic field strength, the proper relationship between electron velocity and resonant frequency may be attained.

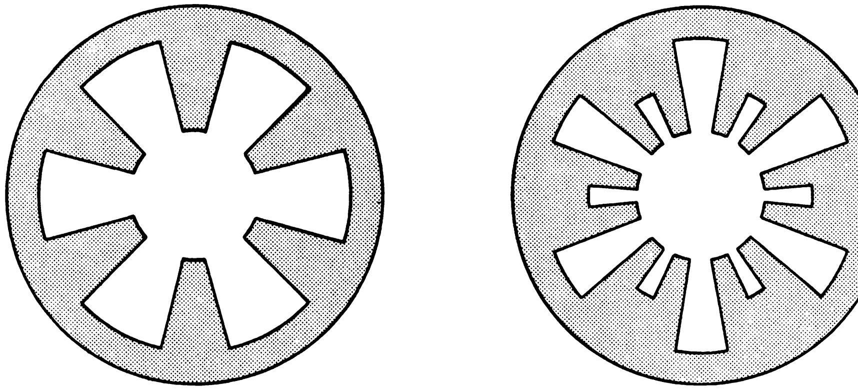
Output Coupling

In multicavity magnetrons, the output coupling is built into the magnetron, where it is not readily accessible for adjustment. The type and the degree of coupling must be fixed in the design and construction of the magnetron. How-



(A) SLOT ANODE

(B) HOLE AND SLOT ANODE



(C) VANE ANODE

(D) RISING SUN ANODE

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Figure 11-26.–Types of anode blocks.

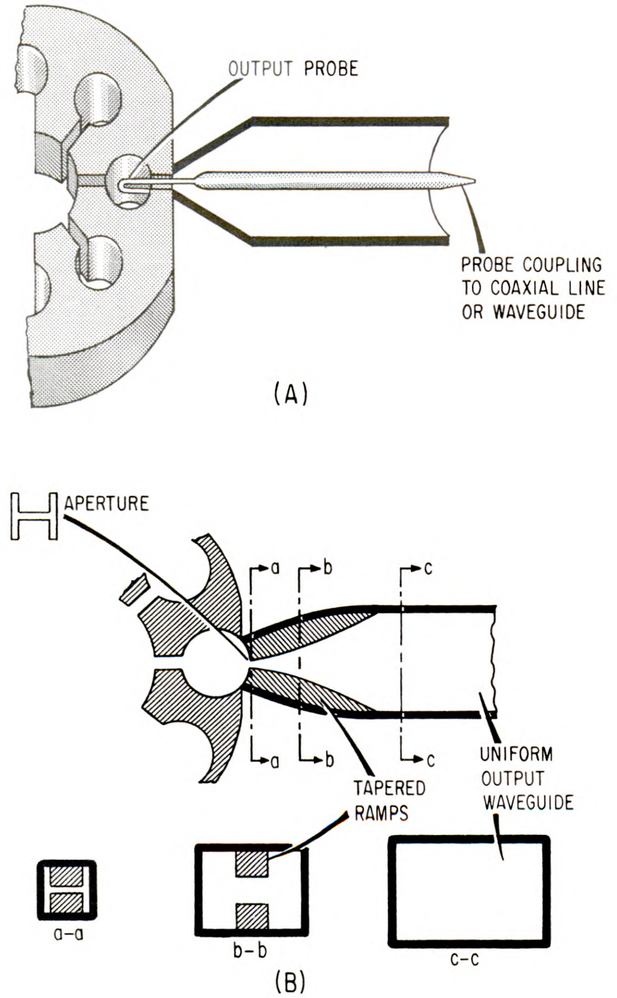
ever, in order for the technician to properly analyze the operation of radar sets, he must have a basic understanding of the function of the coupling devices, the principles involved in the operation of the devices, and the effects they have on the overall operation of the magnetron and the radar set as a whole.

Because the magnetron is highly evacuated, and the waveguide (when used) is usually pressurized, a pressure seal is required where the power is to be taken out of the magnetron. This seal is probably the weakest point in the entire system for voltage breakdown and power output limitations.

Basically, there are two methods for classifying magnetron coupling systems–by the type transmission line involved (coaxial cable or waveguide), or by the type element used for the coupling (loop or aperture).

LOOP COUPLING.–Loop coupling is normally used for transferring energy into coaxial lines. Figure 11-27 (A) shows one example of the loop method of coupling, where the loop is inserted into one of the cavities of the magnetron. The loop is positioned in an intense magnetic field, so that the plane of the loop is perpendicular to the field; thus maximum energy is transferred to the loop.

The transfer of power is affected by the area of the loop and by the leakage inductance. The loop is usually made of a broad strip of copper, and the wall of the cavity is used as part of the loop.



AT.208

Figure 11-27.—Coupling power out of the magnetron.

Coaxial coupling is limited to relatively low power output circuits, due to the limitations of voltage breakdown and arcing imposed by the coaxial cable.

APERATURE COUPLING.—Transferring power from the magnetron into waveguides normally involves aperture coupling. Such a coupling device consists of two main parts—the TRANSFORMING SECTION of waveguide, and the aperture and WINDOW through which the energy passes from the magnetron to the waveguide. (See fig. 11-27 (B).)

If the guide were connected directly to the magnetron, power transfer efficiency would vary rapidly with any change in frequency or loading conditions. The transforming section of the waveguide functions to provide an impedance match between the magnetron and the waveguide. This matching of impedances permits power to be transferred at a relatively constant level of efficiency throughout the entire range of operation. The matching of impedance is accomplished by making the inside of the first portion of the waveguide section the same shape as the aperture, then gradually changing the section until it has the same shape as the waveguide at the end of the transforming section.

The aperture is normally shaped as an H (fig. 11-27 (B)), with the vertical lines corresponding to broad openings in the ends of one of the cavities. The vertical lines maintain a sufficiently high cutoff wavelength to keep operation of the waveguide in the dominant mode. The horizontal line of the H-shaped aperture is the determining factor in the characteristic impedance of the aperture, and represents a narrow slot through the back of the cavity in the anode block. This aperture effectively functions as a capacity-loaded slot.

The window functions as an air pressure seal and as an RF connection between the inner and outer sections of waveguide. A good window must present practically no loss and no reflections. Reflections at the window are kept to a minimum by selecting the material composition (special glass, mica, or ceramic) and by the diameter and thickness of the window. A non-reflecting window may be considered as a short length of waveguide having the same characteristic impedance as the waveguide into which the window is inserted.

The breakdown strength of the window is greater than that of the coaxial output, but is still not adequate for the higher power magnetrons unless the entire system is built for a very efficient power transfer. Any mismatch caused by improper installation, dirt or grease films, excessive moisture, etc., increases the danger of arcing and the resulting loss of power and possible damage to the components. Mica or a special ceramic material is used for the window to improve the power transfer capability of the system.

Additional Features of Magnetrons

In airborne equipments that use a magnetron, the magnetic field is provided by a permanent magnet. Most magnetrons have built-in magnets and are called PACKAGED MAGNETRONS. Thus, whenever a magnetron is replaced, the magnet must also be replaced.

Depending upon the type of magnetron and the type of equipment, it is sometimes necessary to season a new magnetron since it may not withstand the immediate application of full power plate voltage. This is accomplished by subjecting the magnetron for a period of a few hours to filament voltage only. After this warmup period, the plate voltage is applied (at low power settings if possible) and a check is made to determine if the magnetron is arcing. Should arcing be detected, it may be necessary to remove the plate voltage and again subject the magnetron to an additional period of seasoning. The Service Instruction Manual for the specific equipment generally contains information on this phase of maintenance.

Where the magnets are not built in, magnetic polarity should be observed. Theoretically, if the magnetic field of the magnetron is reversed, there should be no change in magnetron operation. This may not always be true since the construction of the magnetron may not be perfectly symmetrical. Thus, if the magnet is removed, it is important that it be reinstalled in its original position. (Generally the polarity of a magnet is indicated, and this may be used as an aid in maintenance.) The magnet should never be removed when the magnetron is operating (nor should the magnetron be operated with the magnet removed) since this would cause electrons to strike the anode at high velocity and result in excessive heating. (With no magnetic field, there is nothing to limit magnetron current.)

The magnetron tube is a delicate unit and must be treated as such. The tube must be handled very carefully. Should it be dropped, or should the tube elements be moved, there is the possibility of a plate to cathode short or a change in spacing of the elements. Either of these will cause the tube to operate improperly or not at all.

Cathodes of magnetrons usually are oxide coated, indirectly heated surfaces. The pulse currents developed are larger than can be produced by thermionic emission alone. The large number of electrons responsible for these currents are developed by secondary emission from the cathode as the cathode is bombarded by high velocity electrons returned by the magnetic field and the RF oscillatory voltage.

Since much of the heating of the cathode is obtained through bombardment of the cathode by the electrons returning to it, the filament voltage is usually reduced after the high voltage is applied. This reduction is accomplished by adding a tapped filament transformer or a series limiting resistor in the circuit. In some equipments the filament voltage is removed completely after anode current reaches a sufficient value.

Metallic cathodes with good secondary emission characteristics have been used satisfactorily. The cathodes are designed with end shields to prevent the escape of electrons from the interaction space between the cathode and the anode block. The magnets, which are made of a special alloy called Alnico, are unusually strong. The field strength required is dependent upon anode potential and operating frequency.

The magnets should not be struck with metallic substances of any hard material because this will cause them to lose some of their magnetism, resulting in a shift in operating frequency, shifting modes of oscillation, and instability of frequency and power output.

Extreme care must be used in handling and even in storing magnetrons. They must not be stored too close together or near other ferrous (magnetic) materials. Carefully observe the instructions in the applicable Service Instruction Manuals and any precautions in or on the shipping container for the magnetrons.

The design of anode blocks determines the frequency and power output. Most anode blocks have cooling fins around the outside for forced air cooling, while other (high power) magnetrons have jackets for liquid cooling.

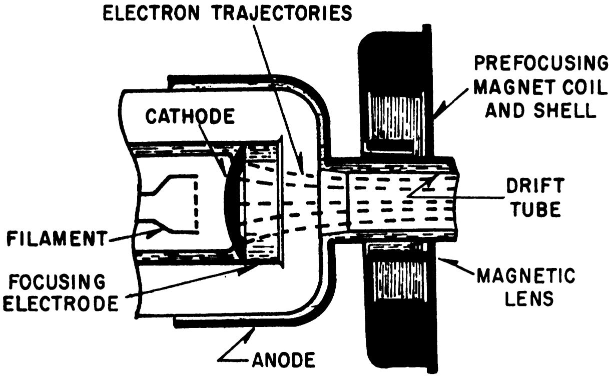
KLYSTRONS

Klystrons depend upon the formation and control of a high velocity electron beam, and are therefore termed VELOCITY MODULATED TUBES. The tube is usually divided into three functional sections–the electron gun, the cavity/drift space region, and the collector. Klystrons are available in low power models and in high power models. They are also available in basic form and in a modified form called the REFLEX

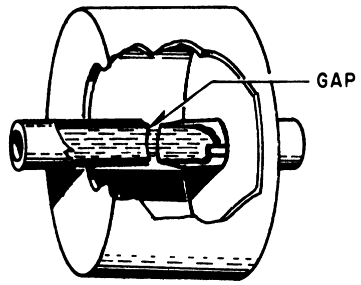
KLYSTRON. They are used almost exclusively at microwave frequencies as oscillators or as amplifiers.

Basic Klystron

The electron beam is simply a fast-moving stream of electrons expelled from the electron gun into the cavity/drift space regions as shown in (A) of figure 11-28. The electrons forming the beam are emitted from a heated cathode, and flow away from the cathode along converging paths created by the specially shaped electric fields formed by the electrodes. These paths converge to form a beam along an imaginary line extending from the cathode through the drift tubes to the collector. This line is termed the KLYSTRON AXIS.



(A)
THE ELECTRON GUN



(B)
CAVITIES OF CATCHER AND BUNCHER REGIONS

AT.209

Figure 11-28.–Klystron. (A) Electron gun; (B) cavities.

The cathode is a concave section of a sphere located inside one end of a cylindrical metal piece called a FOCUSING ELECTRODE. Just beyond the opposite end of the focusing electrode, the anode cup and first cavity/drift space regions are located. The focusing electrode is maintained at the same potential as the cathode, or at some negative potential determined by the anode potential (which is always positive with respect to the cathode). The positive charge applied to the anode causes the electrons to flow away from the cathode toward the anode, and the negative or zero charge applied to the focusing electrode causes the electrons to move in toward the axis. As a result of the two forces acting on the electrons, they form a converging beam which focuses inside the first cavity/drift space region.

The cavity/drift space region of the klystron is made up of the drift tube and two to four resonant cavities which surround it at intervals along its length. The DRIFT TUBE is an axial-interrupted tube in which the electrons are neither accelerated nor decelerated; its length is about 20 times its diameter. Each interruption along the drift tube, called a GAP, forms the entrance to an associated resonant cavity, and is constructed so that the ends of the drift tube sections protrude into the cavity (refer to (B) of figure 11-28) at opposing high voltage points on the cavity wall. Thus the drift tube tips become the capacitive loading elements in the cavity, and large RF voltages are impressed across them when the cavity is excited at resonance. The cylindrical structure forms the inductive element of the cavity. Such cavities are not necessarily cylindrical; some klystrons use gaps surrounded by cylindrical ceramic envelopes that perform the following three basic functions:

1. Maintain a vacuum with a metal-to-ceramic seal.
2. Maintain the proper spacing of the gap.
3. Facilitate the mounting of a detachable rectangular cavity box.

The electron beam transfers some of its energy to the cavities as it flows along the drift tube section of the klystron, and it carries the balance of its energy out of the cavity/drift space region into an electrode called the

COLLECTOR. The collector gathers the electrons after their function has been accomplished and transfers them out of the klystron into the external circuits leading to the positive terminal of the beam power supply. The large energy content of the partially spent beam must be dissipated by the collector. When the electrons collide with the collector surface, all of their kinetic energy is transformed into thermal energy, which heats the collector. The thermal energy is then transferred to the surrounding environment by cooling the collector with a liquid or by air. (See fig. 11-29.)

Figure 11-29 illustrates the assemblies which comprise a typical high power klystron. Frequent reference should be made to this figure during the following discussion.

This high power klystron requires a strong axial magnetic field to maintain and direct the electron beam throughout the length of the drift tube. This axial field is a result of the prefocus coil, the three body coils, and the collector coil shown in (D). (The field could be produced by permanent magnets, although this feature is seldom used in airborne equipment.)

The electron beam tends to disperse because of mutual repulsion between electrons. The axial magnetic field overcomes the tendency by exerting forces on any electrons that try to move in a direction not parallel to the klystron axis. Thus, electrons attempting to leave the axis are forced to remain within the confines of the beam.

At the beginning of its passage through the drift tube, the electron beam is a continuous stream of electrons moving at a constant velocity. Although it is not confined to a wire, the beam is nevertheless considered to be direct current flowing through the free space enclosed by the drift tube. Ideally, the beam would never touch the drift tube, but in practice there are always some electrons which stray far enough from the center of the beam to be caught by the drift tube walls. Just as a direct current produces no detectable sound as it flows through a headphone, a direct-current electron beam can produce no detectable radiofrequency power as it flows through a klystron. It must be changed in some manner before it can be useful. This is accomplished in the klystron at the cavity/drift tube gaps, which change the relative velocity of the electrons comprising the beam.

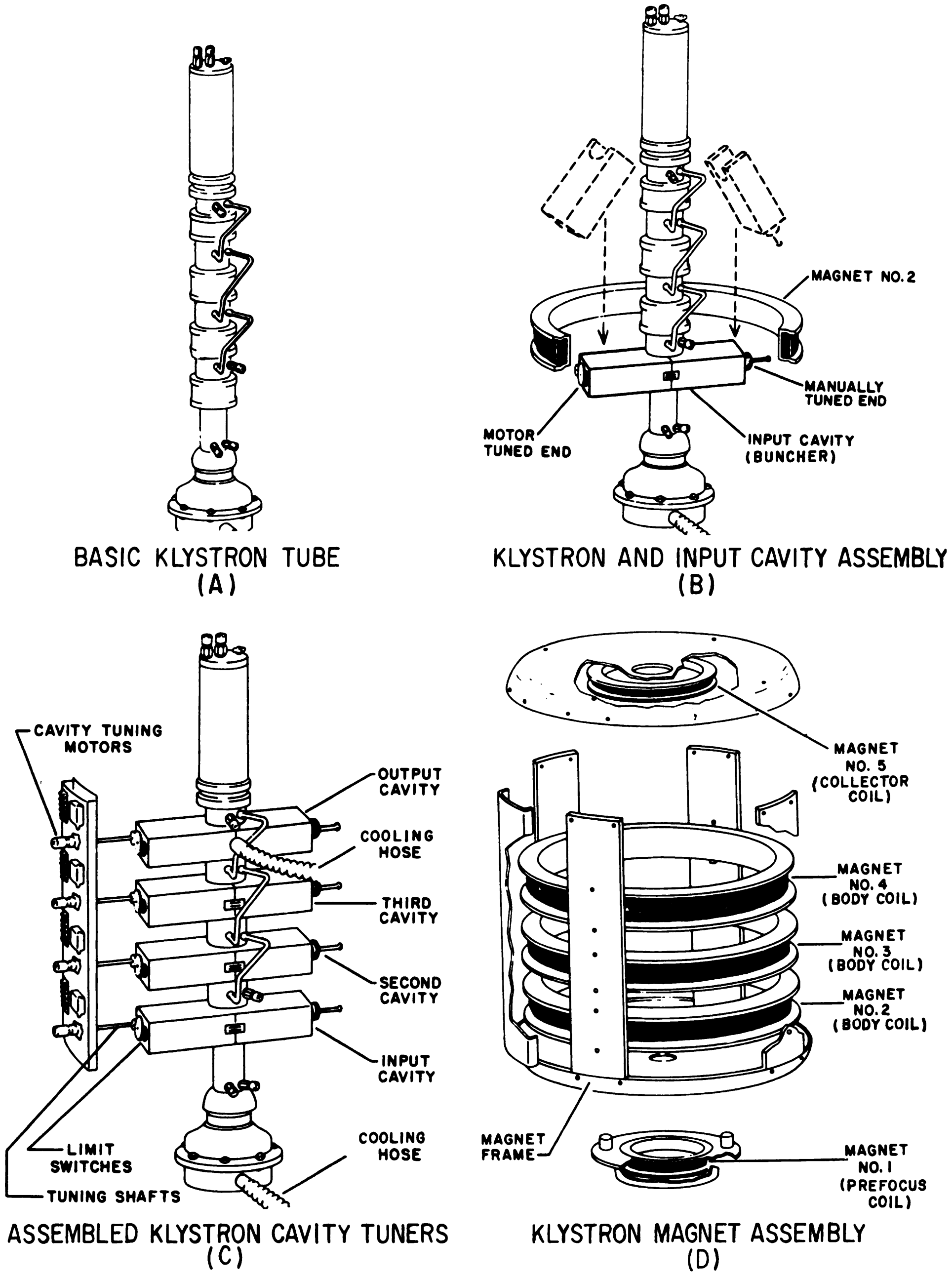
It was previously mentioned that a drift tube gap is formed by the ends of drift tube sections which enter the cavity axially from opposite ends. The cavity is designed so that the drift tube tips become its highest voltage points, in order to build up strong RF fields in the gap (fig. 11-28 (B)).

Consider a single electron after it leaves the electron gun region: see axial electron in figure 11-30. As it approaches the first drift tube gap, often called a BUNCHER GRID, the electron absorbs energy from the high voltage power supply, E_{dc}. Notice that instantaneously both buncher grids are at a high d-c potential with respect to the cathode, but there is no RF voltage between the grids at this time. As the axial electron is accelerated toward the first buncher grid, electrons within the first buncher grid structure tend to move away from the axially moving electron and toward the second buncher grid. The movement of electrons within the buncher grid structures constitutes current flow. An RF voltage is created between the buncher grids (labeled $E_{dc} + E_{ac}$ in fig. 11-30) at the point in time when the axial electron is moving in the plane of the first buncher grid. The instantaneous polarities are also shown in figure 11-30.

When the axial electron has passed the first buncher grid and has moved to a point midway between the buncher grids (gap), its field interacts equally on both grids. Electrons in these grid structures are neither repelled nor attracted at this time, and current ceases to flow. The RF potential between the buncher grids (across the gap) reduce to zero volts. E_{dc}, the high d-c voltage applied to the buncher cavity, however, continues to accelerate the electron toward the second buncher grid.

The axial electron then passes the second buncher grid structure; the electrons tend to move away from the axial electron. This constitutes current flow once again, but this time in the opposite direction (shown as $E_{dc} - E_{ac}$ in fig. 11-30). The maximum value of instantaneous voltage occurs when the axial electron is actually passing through the plane of the second buncher grid.

The axial electron now moves beyond the buncher grids into the drift space region. This electron is now moving faster than before it entered the buncher grids, but it has left a positive



BASIC KLYSTRON TUBE
(A)

KLYSTRON AND INPUT CAVITY ASSEMBLY
(B)

ASSEMBLED KLYSTRON CAVITY TUNERS
(C)

KLYSTRON MAGNET ASSEMBLY
(D)

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Figure 11-29.–High power klystron, assembly.

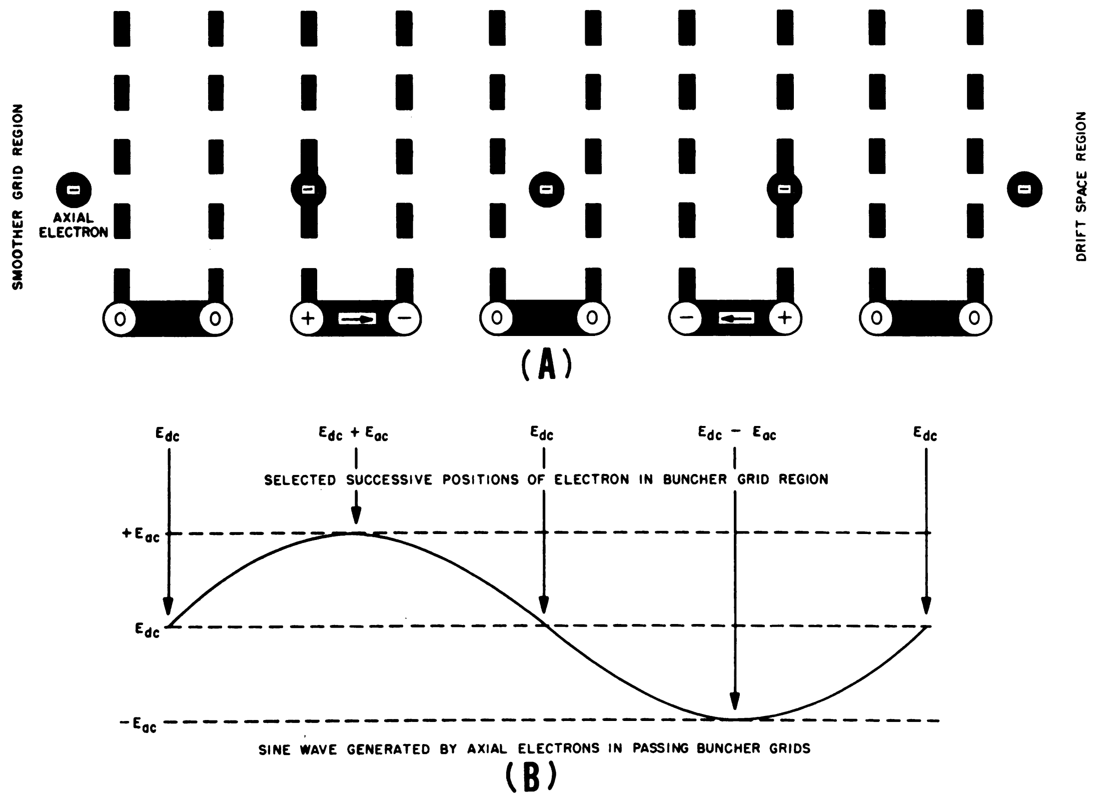
SMOOTHER GRID REGION
AXIAL ELECTRON
DRIFT SPACE REGION
(A)
Edc
Edc + Eac
Edc
Edc − Eac
Edc
SELECTED SUCCESSIVE POSITIONS OF ELECTRON IN BUNCHER GRID REGION
+Eac
Edc
−Eac
SINE WAVE GENERATED BY AXIAL ELECTRONS IN PASSING BUNCHER GRIDS
(B)

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Figure 11-30.–Buncher grid action.

charge on the second buncher grid, due to E_{ac}, and would be attracted backwards if it were not for the velocity and momentum the electron has acquired.

There are three major points of consideration applicable to buncher grid operation. First, the number of electrons leaving the buncher grids is equal to the number of electrons entering the buncher grids; hence, the electron density remains unchanged. Second, the individual velocities of the electrons leaving the buncher grids are higher because of acceleration by E_{dc}, and their exit velocities are higher or lower than the E_{dc} level (by an amount due to the E_{ac} voltage generated by the axially moving electron itself). Third, E_{ac}, created by the movement of the axial electron, varies in a sinusoidal manner. Hence, the exit electron creates the RF field, E_{ac}, which in turn governs the approach velocity of the entry electron.

Since E_{ac} varies in a sinusoidal manner, the preceding axial electrons approaching the buncher grids will be affected as follows:

1. When the sinusoidal voltage, E_{ac}, is positive, it aids E_{dc} in accelerating the axial electron, so that buncher exit velocity is greater than buncher entry velocity.
2. When the sinusoidal voltage, E_{ac}, is zero, E_{dc} is the only acceleration acting upon the axial electron, so that buncher exit velocity relative to E_{ac} is the same as buncher entry velocity.
3. When the sinusoidal voltage, E_{ac}, is negative, it opposes E_{dc} in accelerating the axial electron, so that buncher exit velocity is lower than buncher entry velocity.

Those electrons in the parts of the beam passing the first gap when it is positively polarized experience an increase of velocity because they flow from a region of negative charge toward a region of positive charge. The negative region repels the electrons and the positive region attracts them, with the result that the velocity and energy content of that part of the beam are increased. The energy gained by the faster parts of the beam is provided by the driving power furnished to the input (buncher) cavity (fig. 11-29).

Conversely, the electrons in that part of the beam passing through the first drift tube gap during the half cycles when the polarity is negative are forced to travel from a positive to a negative region. As a result, they will be decelerated and surrender some of their energy to the input cavity.

The beam leaving the buncher cavity is continuous and of uniform density, but alternate parts along its length contain electrons having higher or lower velocities than they had before entering the gap. The faster electrons begin to overtake the slower electrons as the beam travels freely down the axis of the drift tube until, at some point a short distance from the gap, the fastest electrons travel in company with the slowest electrons for a brief period of time. During that period of time, optimum "bunching" occurs. The density of the beam now varies periodically at the signal frequency as observed from a fixed point in space and time. In other words, the beam has now become a density-modulated beam. If a gap is located at the point of optimum bunching, the beam can be made to surrender many times as much energy as was originally required to produce velocity modulation; therefore, the klystron acts as an amplifier.

The function of the catcher grid gap (output cavity, fig. 11-30) is to extract energy from the passing beam of electrons. Energy is extracted from the bunched beam by the same method used to velocity modulate it in the first gap. As the beam travels through the catcher gap, the instantaneous gap polarity varies in such a way that the denser portions of the beam are decelerated and the less dense parts of the beam are accelerated. As the different groups of axial electrons were gated through the buncher grids one at a time, some emerged with high velocities and others emerged with low velocities. As they progressed through the drift space, the two groups caught up with each other. At this instant both groups are intercepted by the catcher grids. Although the average power through the klystron has not changed from buncher to catcher cavity gaps, the instantaneous (peak) power is very high when the catcher cavity gaps intercept the combined energy of the merged groups of axial electrons. As a result, there are many more electrons giving up energy to the circuit than there are electrons absorbing energy, and the net effect is to transfer power from the electron beam to external circuits of the klystron.

The preceding paragraphs have described the action of a two-cavity klystron in which the RF power is used to velocity modulate an electron beam so that it can be made to surrender energy to another cavity after traveling a short distance through the drift tube. Experience has shown the klystron having more than two cavities offer advantages in higher gain and higher efficiency.

There is little or no reverse flow of electrons in the drift tube. The fields in the drift tube which are not due to the presence of the beam are so small that, for all practical purposes, there is complete isolation between the output and input cavities. As a result, it is possible to obtain stable operation from four-cavity klystrons with power gains up to one million.

Reflex Klystron

The reflex klystron does not have a buncher and catcher cavity as separate units; a single cavity is employed. The same pair of grids at the entrance to the cavity acts as a buncher grid at one instant and as a catcher grid at the next instant. The control or smoother grid is operated at a positive potential with respect to the cathode. The cavity grids are operated at a still greater positive potential with respect to the cathode. The repeller plate is operated at a large negative potential with respect to the cathode.

Electrons emitted by the cathode are immediately accelerated to high velocities by the positive potential applied to the smoother grid, and a beam is thereby formed. Consider a group of axial electrons, all with approximately the same energy levels, approaching the cavity grids at the same instant. These axial electrons will be highly accelerated by the cavity grids because of E_{dc}. Notice in figure 11-30 that there is no a-c voltage developed between the cavity grids at this point in time; therefore, E_{dc} is the only accelerating voltage acting upon the electrons.

As the accelerating axial electrons approach the first cavity grid, electrons contained within the metallic cavity-grid structure move toward the second cavity grid because of the mutual repulsion of like charges. The movement of electrons within the grid structures constitutes an electrical current; hence, an instantaneous RF voltage, E_{ac}, is created across the two cavity grids with the polarity shown in figure 11-30. The maximum value of this instantaneous voltage occurs when the axial electrons are actually passing through the plane of the grid structure. The instantaneous polarity of the first cavity grid is now negative, as shown in figure 11-30, and has three effects. First, the effect upon the axial electrons is one of mutual repulsion between like charges. Second, the axial electrons are attracted toward the second cavity grid, which is now positive. Third, any additional electrons approaching the first cavity grid from the smoother grid region will encounter the present negative voltage on the first cavity grid, and their velocity will be reduced because of the repulsion of like charges.

When the axial electrons have moved to a point midway between the two cavity grids, their effect on both grids is equal and the voltage E_{ac} is reduced to zero. These axial electrons, as well as any other electrons approaching the cavity grids from the smoother grid region, are accelerated by a gain-absorbing power from the high voltage power supply.

As the axial electrons approach the second cavity grid, an instantaneous current flow is created once again, but the polarities of the two cavity grids are reversed. The maximum value of E_{ac} occurs when the axial electrons are actually in the plane of the grid structure.

As the axial electrons move away from the second cavity grid, the instantaneous voltage E_{ac} is reduced to zero again. Hence, an alternating voltage is created when the axial electrons move past the cavity grids. This RF voltage causes a change in the velocity of other electrons attempting to pass through the cavity grids.

When the electrons enter the drift space, they come under the influence of the repeller plate. This plate is operated at a highly negative potential with respect to the cathode. Its value is not necessarily fixed, but is so considered during this discussion. Those electrons which were gated through the cavity grid region when E_{ac} was positive possess high velocities and have acquired enough energy to travel far into the drift space, resisting the forces of mutual repulsion centralized at the repeller plate. Eventually, the electron velocity will be reduced to zero, and the electrons will then be attracted back to the cavity grids. (See figs. 11-31 and 11-32.)

Those electrons which were gated through the cavity grid region when E_{ac} was negative not only have low velocity and energy levels, but also passed the grids a half cycle later in time. These low velocity electrons will not travel very far into the drift space region before their velocities are reduced to zero by the forces of mutual repulsion centralized at the repeller plate. (See fig. 11-32.)

Both the fast and the slow axial electrons will be reduced to zero velocity at the same time, but they are widely separated in physical distance. At this point in time consider the forces acting upon the two electrons in the drift space. First, there is the stationary electron located very near the highly negative repeller plate. The forces of attraction centralized at the cavity grids tend to pull this electron back to the grids, but this is very slight compared to the forces of repulsion centralized at the repeller plate. Hence, the electron that originally had a high velocity will be accelerated to high velocity again but toward the cavity grids. Second, there is the stationary electron located very near the highly positive cavity grids. The forces of attraction for this electron are very high, while the forces of repulsion centralized at the repeller plate are comparatively weak. This electron is also attracted back toward the cavity grids, but its velocity is still low. Eventually, the high velocity electron overtakes the low velocity electron, and ideally the cavity grids should be located at the point where this action occurs.

The first and second cavity grids now act as a catcher grid to extract the energy from both electrons as they move past the two grid structures. After the electrons emerge on the other side of the cavity grids, they are once more in the region of the smoother grid. Because of their high velocity and mutual repulsion with respect to the electron beam formed by the smoother grid, these high velocity electrons are deflected toward the shell or body of the klystron (also at a positive potential with respect to the cathode), where they are returned to

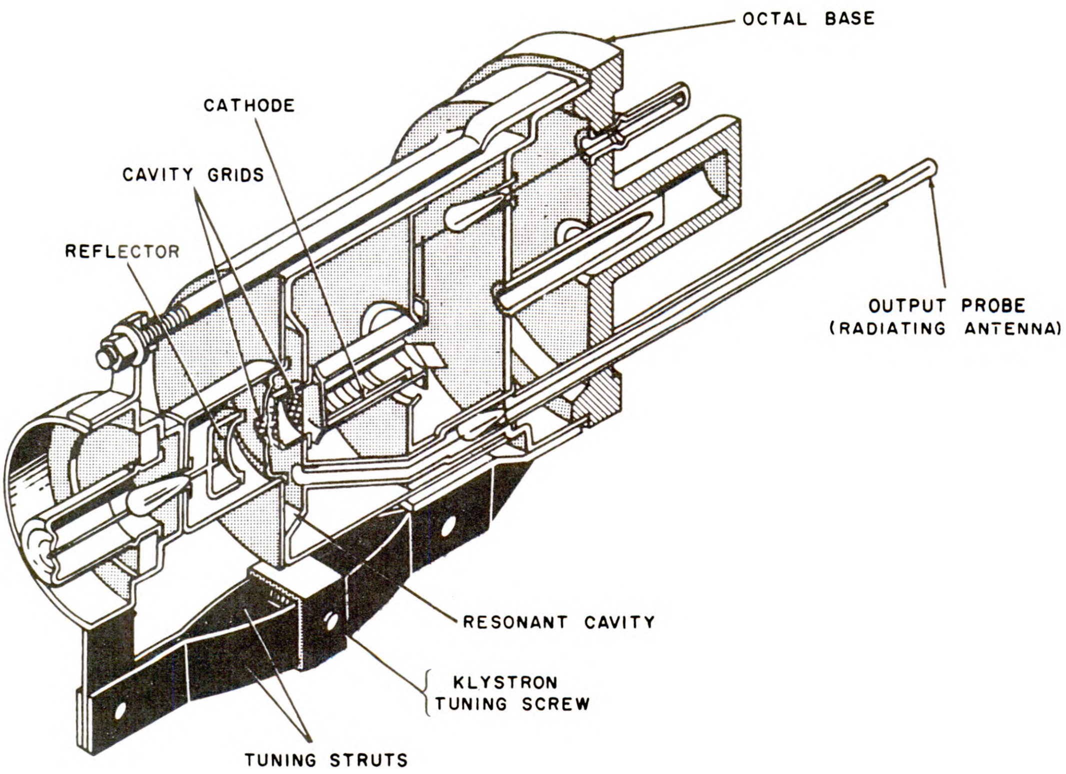

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Figure 11-31.–Reflex klystron, cutaway view.

the plate power supply. The energy extracted by the cavity grids is coupled by the resonant cavity to the output terminals of the klystron.

It was previously stated that the repeller plate voltage was not necessarily fixed. When an alternating voltage such as an audiofrequency is applied directly to the repeller, the rate at which the axial electrons are repelled changes; consequently, the output frequency of the klystron changes or deviates from its average value. This is known as frequency modulation.

In radar equipments using klystrons as the local oscillator, the repeller plate voltage is frequently varied so as to change the frequency of the oscillator. This is the function of the automatic frequency control.

PLUMBING

Many additional microwave components and devices are required to perform specific functions. As a group, these devices are commonly called microwave plumbing devices. Most of these devices make use of sections of waveguide, with internal characteristics and connection methods designed to produce the desired results. This section is devoted to a brief discussion of microwave plumbing devices used for the following purposes:

1. Changing the direction of the signal path (bends, twists, and joints).
2. Connecting signal paths (junctions and couplers).
3. Switching signal paths (duplexer systems).
4. Matching impedances (terminations, reactive devices, and attenuators).
5. Modulation and demodulation of microwave signals (mixers).

Following this section is a brief discussion of the ferrite devices used in microwave systems.

Changes in Signal Path

It is impractical to construct a complete microwave system for an airborne radar set in one straight piece. In an airborne installation,

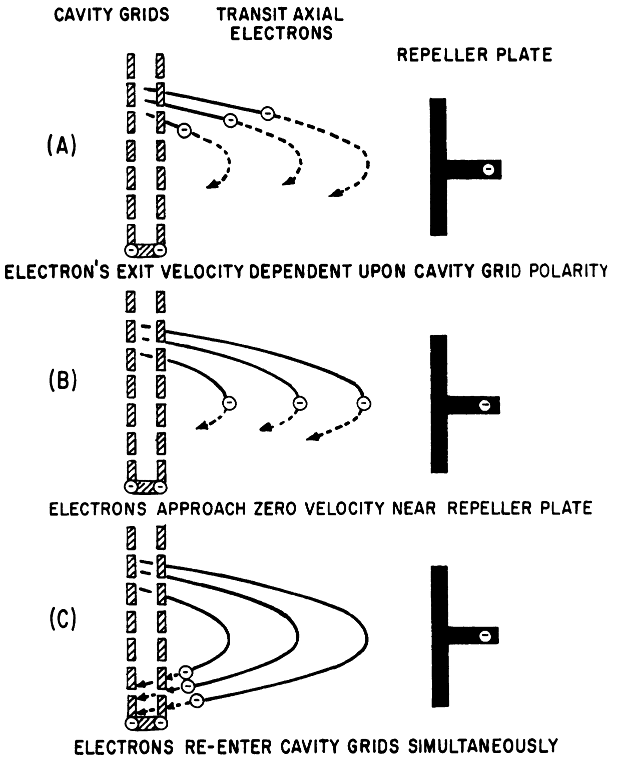
CAVITY GRIDS
TRANSIT AXIAL ELECTRONS
REPELLER PLATE
(A)
ELECTRON'S EXIT VELOCITY DEPENDENT UPON CAVITY GRID POLARITY
(B)
ELECTRONS APPROACH ZERO VELOCITY NEAR REPELLER PLATE
(C)
ELECTRONS RE-ENTER CAVITY GRIDS SIMULTANEOUSLY

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Figure 11-32.–Drift space action in reflex klystron.

each microwave assembly must be mounted in an appropriate location, and the waveguide routed so as to connect them. This requires the use of various bends, twists, and joints in the waveguide structure. (See fig. 11-33.)

In order to transmit energy from one end of a waveguide to the other without reflections or losses, the size, shape, dielectric material, and direction must be constant throughout its entire length. Any abrupt change results in reflections and associated energy losses. By keeping all such changes gradual, the undesirable results can be minimized.

BENDS AND TWISTS.–A gradual bend or twist must have a radius of curvature greater than two full wavelengths in order to minimize reflections. Although the change in direction may be any amount, it is usually made in steps not exceeding 45° each.

A bend is used to change the direction of signal path without changing the orientation of the signal and associated fields and thus the mode of operation. A bend may be made in either the narrow or the wide dimension. When it is desired to rotate the electromagnetic fields, a twist is inserted. Gradual twists are normally used in order to minimize reflections.

When it is necessary that a change be abrupt, special devices must be used. Normally, in a sharp bend, reflections occur and result in considerable power loss. In order to avoid this, the guide is bent twice, at 45° each, a quarter wave apart. The first bend results in a reflection; the second also results in a reflection, but inverted. The combination of the direct reflection and the inverted reflection cancels, leaving the field oriented as though no reflection has occurred.

FLEXIBLE WAVEGUIDE.–To permit use of any special bend or twist required by a specific installation, some sections of waveguide may be made flexible. These sections can be bent or twisted within limits (in most cases the minimum radius of bend or twist is greater than two wavelengths). Because of their flexibility, these sections also help to absorb vibration, permitting shock mounting of units rather than requiring rigid mounting.

Flexible waveguide sections usually consist of a spiral-wound ribbon of brass, the winding having the same cross-section dimensions as the waveguide into which it is inserted. Skin effect keeps current flow at the inner surface; to provide for maximum conductivity, the inside surfaces of the flexible winding are silver plated. To retain flexibility while providing airtight and moistureproof construction, the outside surface is covered with rubber or a flexible insulation material.

Although bends and twists may be incorporated into rigid sections of waveguide, they are often supplied as separate sections, which must then be connected to the main waveguide by joints. Flexible waveguide sections must always be connected to rigid waveguide sections by joints.

JOINTS.–It might seem that joining two sections of waveguide would require only that the sections be the same size and fit tightly at the joint. Irregularities at the joint, however, could set up standing waves and result in energy leakage and dissipation of power.

PERMANENT JOINTS are used only in waveguide sections which do not require disassembly. During the manufacturing process at the factory, the sections are machined to close tolerances, welded together, and smoothed to a mirror finish on the inside surfaces. This process results in a hermetically sealed joint which has negligible effect on the fields.

If maintenance procedures require that the two sections be disconnected, semipermanent joints are normally used. The most common semipermanent joint is the CHOKE JOINT, illustrated in figure 11-33 (B). The joint consists of two mating flanges, one flat and the other slotted, which connect the waveguide sections at their center. The slot is a quarter wavelength deep at a distance of a quarter wavelength from the point where the walls of the waveguide are joined.

The quarter-wave slot is shorted at the end; the distance down one side and back up the other side is effectively a half wavelength. Thus, the short circuit reflects a short at the point where the walls are joined. Electrically, this creates a short at the junction of the two waveguide sections.

The two sections could actually be separated from each other by as much as one-tenth of a wavelength without creating excessive standing waves or energy loss. Such a separation leaves room to insert a pressurizing seal at the joint. When a seal is to be inserted, the quarter-wavelength distance from the walls to the slot is modified slightly to compensate for the reactances introduced.

In most airborne radar systems, the transmitter is mounted stationary while the antenna must be free to scan or to rotate. This feature requires a ROTATING JOINT, which separates the sections mechanically while efficiently connecting them electrically. (See fig. 11-33 (C).) In a circular waveguide operating in a mode such as $TM_{0,1}$, the fields are symmetrical about the axis. In this system, a simple choke joint may be used; the waveguide rotates, but the field orientation remains fixed. Since the field remains effectively undisturbed, reflections are held at a minimum.

Although this method is satisfactory in theory, most airborne systems use rectangular waveguides, thus requiring a different type of joint. A coaxial cable provides the axial symmetry required for the fields, and also provides the circular cross section required for rotation. In the rotating joint, a probe is the center conductor of the coaxial section. The probe extracts energy from one waveguide section, conducts it through the cable, and injects it into the other waveguide section.

The center conductor is fixed in relation to the stationary section, and the rotating section revolves around it. For electrical connection, the outer conductor can either be fitted with sliding contacts or coupled to the tubing by a half-wave slot. The slot, which is shorted at the end, reflects a short circuit at the junction of the outer conductor sections. With this method, no mechanical connection is required between the outer conductors. The inner conductor of the coaxial section may be supported by insulating washers, if required.

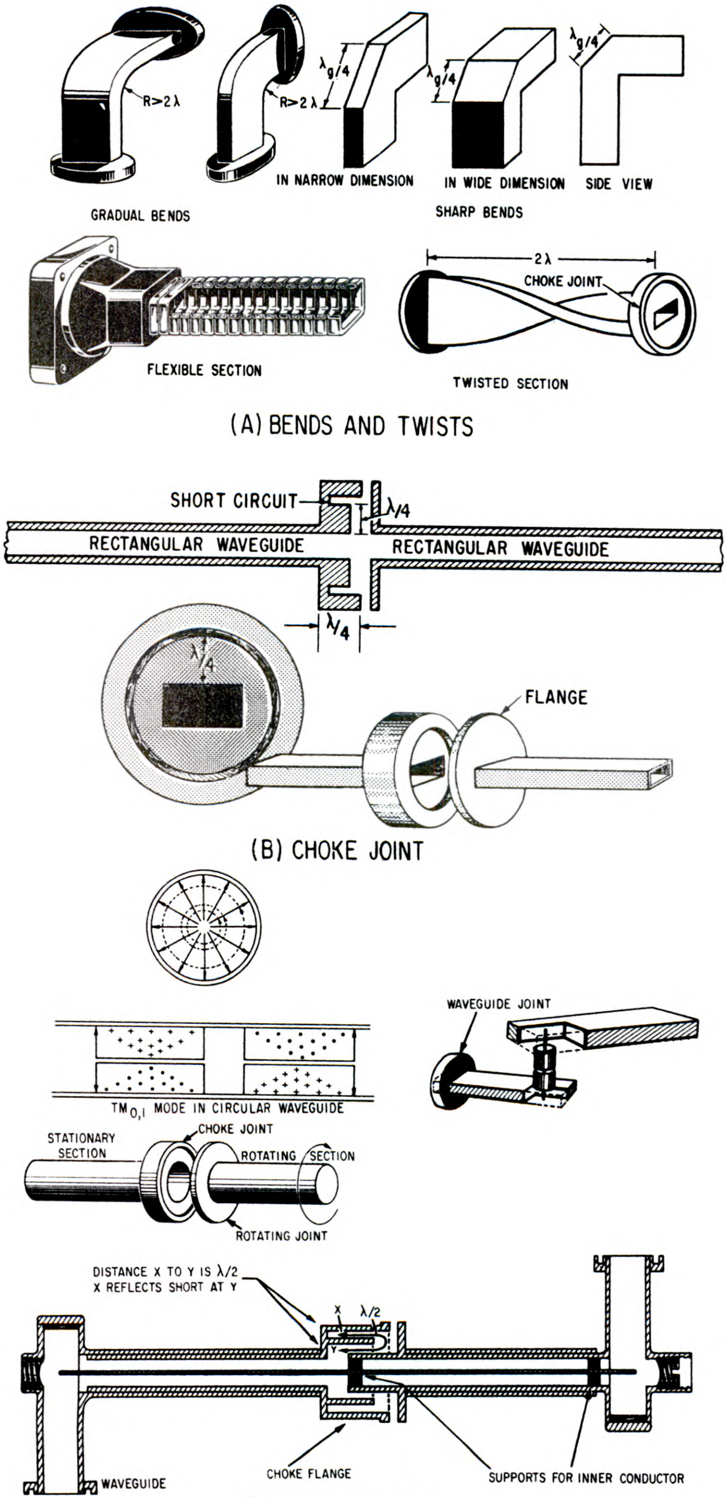
Connecting Signal Paths

Most microwave systems require multiple paths for signal transfer. The connection of signal paths is normally accomplished by the use of junctions and couplers.

JUNCTIONS.–When a section of waveguide is connected into the side of another waveguide, the connection is normally referred to as a T-junction. The junction may be made in either the wide or the narrow side, as indicated in figure 11-34 (A) and (B). When the junction is made in the plane of the H-lines, it is called an H-TYPE junction; when in the plane of the E-lines, it is an E-TYPE junction.

The H-type junction (fig. 11-34 (A)) is effectively a parallel connection with the main line. When the end of the T-section is short circuited at a distance of a half wave from the center of the waveguide, the result is an equivalent parallel circuit. This section will reflect a short circuit at the line and will not allow any energy to pass. Similarly, in the waveguide itself a short circuit is reflected to the center where the E-lines are supposed to be. Since an E-line cannot exist at a short circuit, no energy will pass that point. If the shorted end of the T-section were only a quarter wave from the center of the waveguide, an open section would be reflected there and the passage of energy would be unaffected.

The E-type joint (fig. 11-34 (B)) is effectively a series connection with one side of the main line. In this case, if the section added to the waveguide is a half wave long, it will act as a



(A) BENDS AND TWISTS

(B) CHOKE JOINT

(C) ROTATING JOINT

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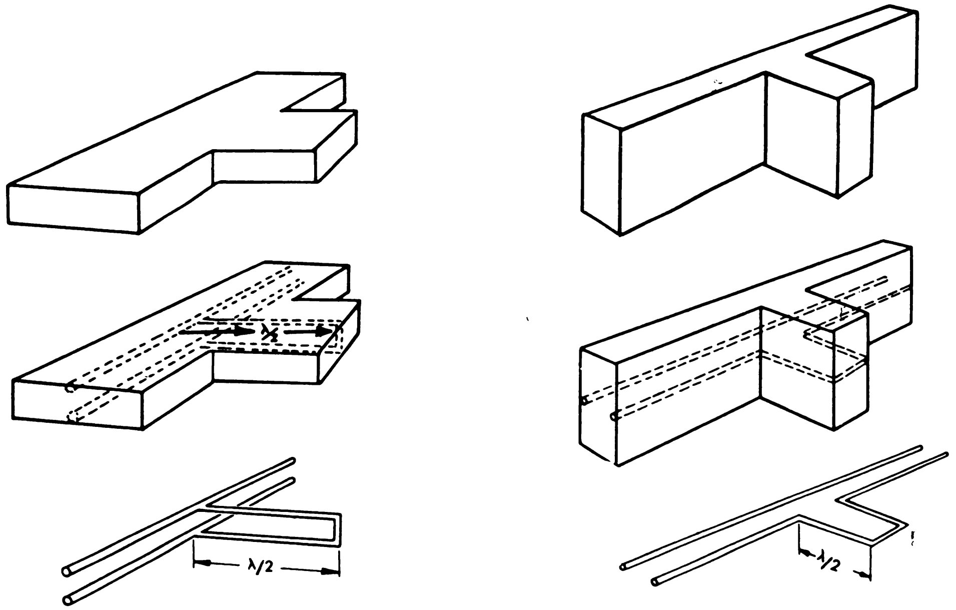
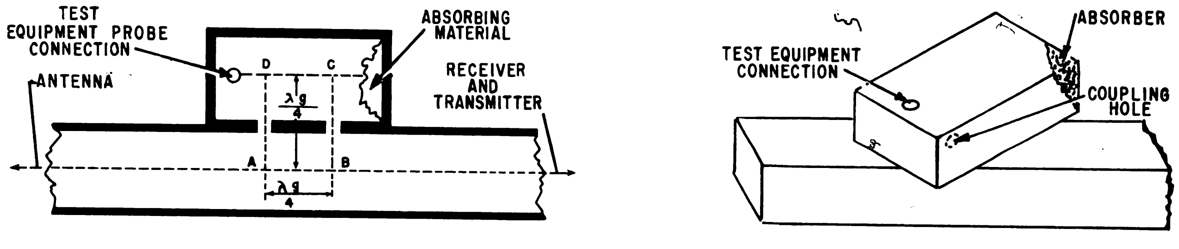
Figure 11-33.–Waveguide bends, twists, and joints.



(A) H-TYPE T-JUNCTION FOR $TE_{1,0}$ MODE

(B) E-TYPE T-JUNCTION FOR $TE_{1,0}$ MODE



(C) TWO-HOLE DIRECTIONAL COUPLER

(D) ONE-HOLE DIRECTIONAL COUPLER

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Figure 11-34.—Junctions and couplers.

short at the junction and will allow the energy to pass. The length of the added section must be a quarter wave in order to open the circuit at the junction and stop the ordinary flow of energy.

COUPLERS.—Directional couplers are devices used to couple energy into or out of waves traveling in one direction without affecting energy traveling in the opposite direction in the same waveguide section. They are normally included as a permanent section of waveguide, but in some equipment they are detachable. They are used in the measurement of power, such as radar transmitter power output as measured in the waveguide. They are also used to inject a signal of known power into the waveguide in order to measure receiver sensitivity. Signal transfer is effectively accomplished by aperture coupling of the electromagnetic fields.

Directional couplers normally have a fixed amount of attenuation and characteristic impedance, which are stamped on the coupler. They contain no moving parts, and inject negligible reflection into the waveguide. Thus, they are effective in matching the impedance of the test equipment to that of the waveguide, and vice versa.

In a two-hole coupler (fig. 11-34 (C)), a wave traveling to the right in the main guide has two paths to the probe in the coupler section. One path is from A to D directly; the other is from

A to D via the path B-C. The two paths differ in length by a half wavelength, so that signals arriving by both paths are 180° out of phase and cancel. Any signals traveling to the right in the upper section are in phase, but are lost in the absorbing material.

If the wave in the main guide moves to the left, the two paths by which waves arrive at point D (path BCD and path BAD) are equal in length, and a wave proceeds to the left in the upper guide and is picked up by the test equipment probe. The absorbing material receives little or no energy, since waves to it (paths BADC and BC) cancel. Thus, energy from the transmitter passing to the left in the guide will reach the test equipment connection with a desirable amount of fixed attenuation, but energy picked up by the antenna and passing to the right will not reach the test equipment.

A signal injected at the test equipment probe can travel toward the receiver (which is between the directional coupler and transmitter) but cannot pass to the left toward the antenna.

A one-hole directional coupler is shown in figure 11-34 (D). Coupling from the main guide to the branch is accomplished by the electric and magnetic fields. The phase of the magnetic field is changed by the coupling so that the waves in the branch are canceled in one direction and reinforced in the other. In contrast to the two-hole coupler, the one-hole coupler transmits a wave in a direction opposite to that of the wave in the main line. Proper coupling to obtain the desired directional characteristic depends on the orientation angle between the main guide and the branch guide and the size of the hole between the two guides.

The branch guide is terminated at one end with a resistive material to absorb unwanted power; the other end contains a probe for connection to the test equipment.

Switching Signal Paths

In microwave systems it is sometimes necessary to switch signal paths within a complex system with several modes of operation. One common example of this requirement is found in the waveguide network used with radar antennas. The same antenna is used for transmission and reception, and energy flow in the antenna feed system must be efficient. During transmission, a very high level of energy must flow from the transmitter to the antenna for radiation. During reception, received echoes (which have a very low energy level) must flow from the antenna through the same waveguide to the receiver.

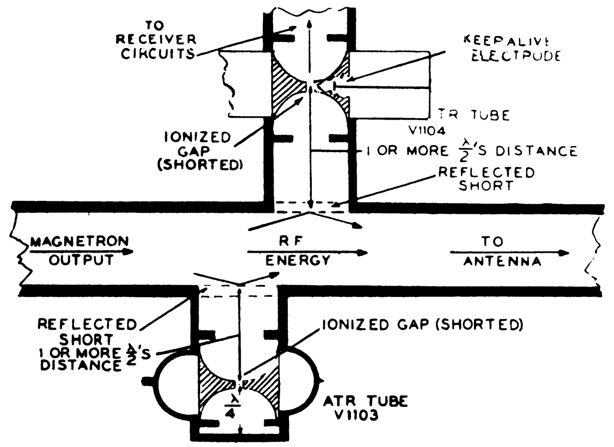
Although the directional couplers previously discussed are capable of switching signal paths, they are not adequate for this task. The power level of the transmitter signal would permit enough leakage through the coupler to damage the sensitive receiver input circuits. The coupler would also permit excessive leakage of the received signal into the transmitter, decreasing the effective overall sensitivity of the system.

In a radar system, the receiver must be disconnected from the signal path during transmission, and the transmitter must be disconnected during reception. Due to the short period of time available for the switching action, the switching device must be automatic and very fast acting. Such a device commonly used in airborne radar systems is the DUPLEXER. A simplified cross sectional view of a waveguide system duplexer is shown in figure 11-35.

The illustrated system consists of a main waveguide section between the transmitter and the antenna, with two branches attached through T-junctions. One branch leads to the receiver, and a TR tube is inserted in this branch. The other branch contains an ATR tube. In most systems the TR and ATR tubes are of the same type; differences in their operation result from differences in installation.

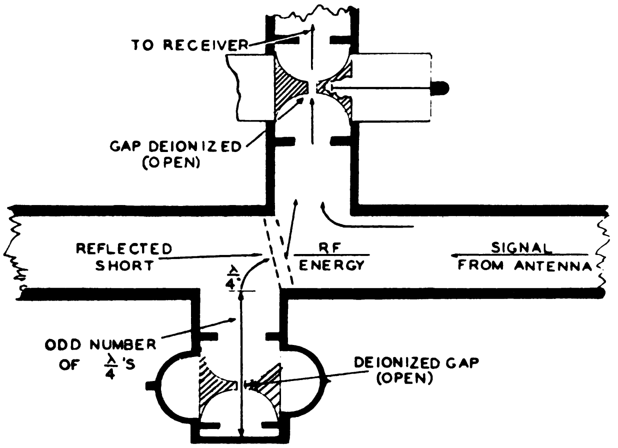
TUBE CHARACTERISTICS.–A TR tube is effectively a gas-filled spark gap tube with three electrodes. Two of the electrodes comprise the main gap (which does the switching); the third electrode is called the keep-alive electrode. The keep-alive electrode is mounted close to one of the main gap electrodes, and is supplied with a relatively high d-c potential.

At sea level pressures of air, approximately 30,000 volts (called the breakdown voltage) are required to break down a spark gap of 1 inch. Once the arc is established, approximately 50 volts (called the running voltage) are required to sustain ionization. Once the running voltage is removed, a period of approximately 10μ sec (called recovery time) is required for deionization. By enclosing the spark gap in a partially evacuated envelope and substituting an appro-



TRANSMISSION OF PULSE

(A)



SIGNAL RECEPTION

(B)

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Figure 11-35.–Waveguide system duplexer.

priate gas for the air, the breakdown voltage, running voltage, and recovery time may be reduced. Application of the proper keep-alive voltage keeps the TR tube on the verge of ionization. Thus the magnitude of the ignition spike and the pulse duration may be reduced, while at the same time insuring almost instantaneous firing of the tube for each pulse of the magnetron.

ASSEMBLY OF COMPONENTS.–For optimum overall system efficiency, the power dissipated in the TR and ATR tubes must be minimized. The tubes must maintain a properly matched line while fired; at the same time, they must afford adequate attenuation to prevent excessive leakage into the alternate signal paths. The manner in which these requirements are fulfilled depend on the assembly and tuning of the individual components of the duplexer system (fig. 11-35).

The TR tube is placed an even number of quarter wavelengths from the waveguide. A short circuit existing within the tube reflects an effective short at the entrance of the receiver T-junction. This short prevents the RF pulse from reaching the crystal and receiver circuits, but allows the pulse to proceed unimpeded to the antenna.

The ATR tube is also located an even number of quarter wavelengths from the waveguide. When the transmitter fires, the gap of the ATR tube breaks down and an effective short circuit is reflected across the opening at this T-junction. The wall of the waveguide appears continuous, and the pulse of energy from the transmitter passes unimpeded.

The ATR waveguide section is constructed so that an odd number of wavelengths exists between its shorted end and the opening to the main waveguide. Normally, the tube is deionized, and an effective open circuit appears at the T-junction. A short circuit is thus reflected across the waveguide adjacent to the TR opening (a quarter wavelength away), as shown in figure 11-35 (B). The received signal is thus guided into the TR opening instead of proceeding to the transmitter.

Matching of Impedances

In order to effectively transfer energy throughout an entire waveguide network, it is necessary to maintain a proper impedance match at each transfer point. At every place where waveguides, cavity resonators, or any of the coupling devices are to be joined, the impedances of the input and output devices must be matched for best (but not necessarily maximum) transfer of energy. Improper impedance matching results in undesirable standing waves, loss of power, and decrease of operating efficiency.

The basic principles of impedance matching are discussed in chapters 4 and 12 of Basic

Electronics. A thorough review of these principles may prove helpful before proceeding with this discussion.

The characteristic impedance (Z_0) of a waveguide is not as easy to define as that of a coaxial line. The characteristic impedance of a waveguide is approximately equal to the ratio of the strength of the electric field to the strength of the magnetic field. This ratio is equivalent to the voltage to current ratio in coaxial lines on which there are no standing waves.

The lowest characteristic impedance of a circular waveguide is about 350 ohms. In a rectangular waveguide, it may be any value, depending on the dimensions of the waveguide and the frequency of the electrical energy. In this guide, it is directly proportional to the narrow (b) dimension when the wide (a) dimension and the frequency are fixed, and may vary from approximately 0 to 465 ohms.

On a waveguide there is no practical place to connect a fixed resistor to terminate it in its characteristic impedance as there is on a coaxial cable. However, there are a number of special arrangements which accomplish the same purpose.

In many cases it is desirable to match the impedance of the guide in order to insure a minimum of reflection. On the other hand, there are many instances where it is desirable for all the energy to be reflected from the end of the waveguide. Both of these, and some other methods of matching or modifying impedances of the guides, are discussed below.

MINIMUM REFLECTIONS.–One method of terminating a waveguide for minimum reflections consists of filling the end of the guide with a graphite-sand mixture, as shown in (A) of figure 11-36.

As the fields enter the mixture, currents flow in it and create heat, which is instrumental in dissipating energy. None of the energy thus dissipated as heat is reflected back into the guide.

Another method for terminating a waveguide is to use a wedge of high resistance as shown in (B). The plane of the wedge is placed perpendicular to the H-lines. When the H-lines cut the wedge, a voltage is induced; the current produced by the induced voltage produces an I^2R loss. Similarly, E-lines produce current flow and an I^2R loss. These losses are dissipated in the form of heat, and very little energy is permitted to reach the closed end to be reflected.

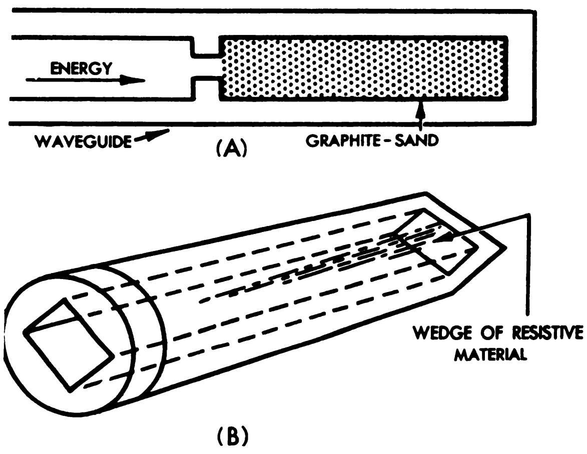

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Figure 11-36.–Termination for minimum reflections.

These terminations are used as transmitter dummy loads for testing and shop operation. They are generally constructed with external cooling fins for better heat dissipation.

MAXIMUM REFLECTIONS.–When it is desirable to terminate the waveguide in such a manner as to obtain maximum reflection of energy from the end of the waveguide, there are several methods that may be used. Some of these are shown in figure 11-37.

One method is to weld a permanent metal shield (plate) at the end of the waveguide, as shown in (A). When it is necessary that the end be removable, a removable end plate is attached to the end of the guide. For this method to be satisfactory, the contact between the guide and the end plate must be exceptionally good in order that the H-field will not be attenuated when current flows.

Perfect contact is not required when the connection is made at a point of minimum current. (This point is located a quarter wave from the end.) When connection is made at this point, a cup is used (as in (B)) instead of the end plate. This cup is a quarter wave long and large enough to fit over the end of the guide. The voltage between opposite sides of the cup opening is high; but as the reflected H-field cancels the incident H-field, the resulting current is very small and power loss is at a minimum.

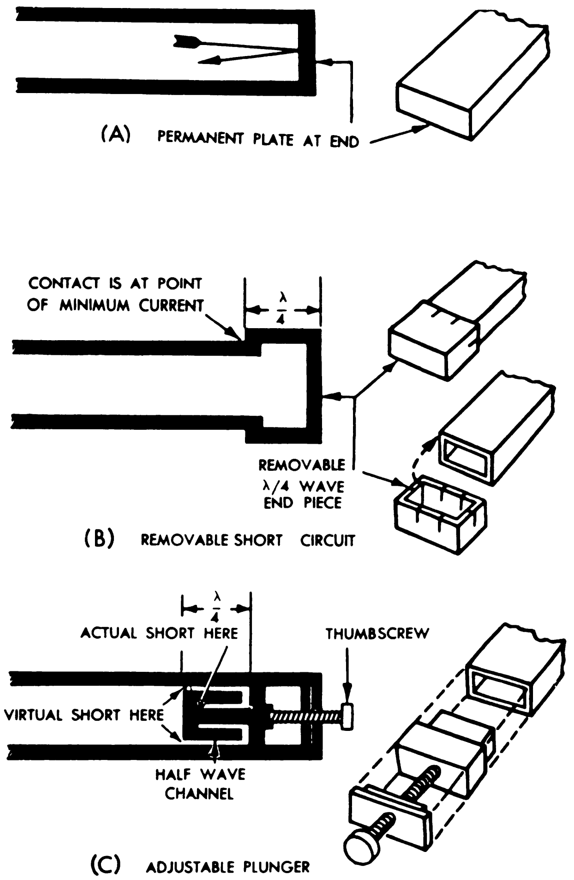
(A) PERMANENT PLATE AT END
CONTACT IS AT POINT OF MINIMUM CURRENT
λ/4
REMOVABLE λ/4 WAVE END PIECE
(B) REMOVABLE SHORT CIRCUIT
λ/4
ACTUAL SHORT HERE
THUMBSCREW
VIRTUAL SHORT HERE
HALF WAVE CHANNEL
(C) ADJUSTABLE PLUNGER

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Figure 11-37.—Termination for maximum reflections.

When the end must be adjustable, the contact must be nearly perfect. However, it is impossible to get a perfect contact. The best arrangement, one which is similar to the choke joint previously explained, consists principally of an adjustable plunger which fits into the guide as shown in (C). The walls of the waveguide and the plunger form a half-wave channel. The half-wave channel is closed at one end and reflects a short circuit across the other end, where a perfect connection is supposed to exist between the wall and the plunger. The actual physical contact is made at a quarter-wave distance from the short circuit, where the current is minimum due to the standing waves. This makes it possible for the plunger to slide loosely in the guide at a point where the contact resistance to current flow is very low.

REACTIVE DEVICES.—Some devices which are used in radar introduce inductance or capacitance into the circuit. Sometimes these reactances are deliberately introduced. Other times when they are present and not desired, they can be tuned out with small fins or plates in a waveguide.

Figure 11-38 shows a number of reactive plates which are deliberately used to introduce capacitance or inductance into a waveguide. In (A) the edges of the plates are parallel to the E-lines. The electric field causes current to flow along the edges. The current flow causes a magnetic field to be generated, and thus the partition acts as an inductance. The partition also causes higher order modes; but since the waveguide is too small for these modes, they are rapidly attenuated and are not propagated. This causes a small loss of power. The amount of inductive reactance produced by these plates depends on the spacing between them. The wider the spacing, the greater the inductive reactance, and the smaller the effect on the fields.

In (B) the edges of the plates are at right angles to the E-field. Electrons accumulate first on one edge and then on the other, and the plates act as a capacitor. Higher modes are produced (as with the inductive plates); and the wider the spacing between the plates, the greater the capacitive reactance.

From these facts it would seem that a resonant circuit might be produced by combining both types of plates and leaving a small opening in a large guide, as shown in (C). This is approximately true, provided that the dimensions are correct. Such a waveguide would, in effect, have a parallel resonant circuit connected across it.

Mixing Microwave Signals

The usual function of the mixer in a superheterodyne receiver is to combine the frequency of the incoming signal with that of the local oscillator, and to produce from this combination a third (IF) frequency. The IF is usually much lower than either of the two input frequencies. The IF is then amplified and used to carry the impressed intelligence through the rest of the RF circuits. (The basic principles of superheterodyne receivers are discussed in Basic

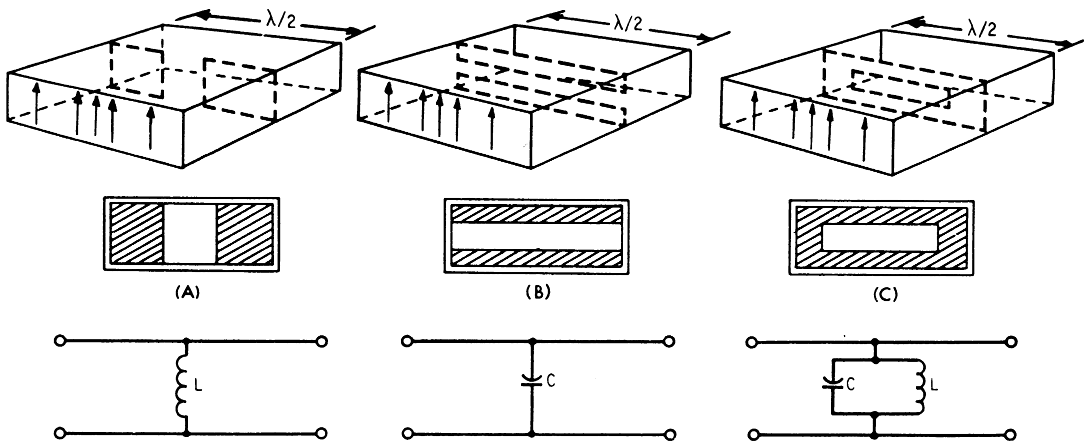

Figure 11-38.–Reactive plates in waveguide, $TE_{1,0}$ mode.

Electronics.) Use of vacuum tube mixers is usually restricted to receivers in and below the UHF range. At microwave frequencies, the mixer is almost always of the crystal type.

Crystals are extremely delicate, and must be well protected by the TR device as discussed previously. Echo signals of a microwave radar system, after passing through the TR device, are applied to the crystal mixer. Local oscillator voltage is also applied to the mixer. Signals at the intermediate frequency are derived at the mixer output during the time of each return echo.

SINGLE-ENDED MIXERS.–Figure 11-39 illustrates the important features of a single-ended mixer used in the 10-cm frequency range with coaxial line inputs. Part (A) is a cutaway pictorial representation; part (B) illustrates the equivalent circuit.

Echo signals are coupled into the transmission line section between the TR cavity and the crystal by means of a coupling loop which penetrates a short distance into the cavity. The crystal fits snugly into the inner conductor of the line and is held concentric with the outer conductor by means of a dielectric bead. The local oscillator signal is introduced into the mixer assembly by means of a coupling probe located approximately a quarter wave (at the local oscillator frequency) from the coupling loop in the TR cavity. A high impedance in the direction of the cavity is thus presented to the local oscillator signal at the probe. The strength of the local oscillator signal at the crystal may be changed by varying the distance the probe extends into the main line. Power from the local oscillator is conducted to the probe via a section of transmission line.

Connection between the crystal and the inner conductor of the line section carrying IF signals is provided by a spring contact. The half-wave RF choke appearing on the IF side of the crystal provides an electrical short circuit for radio-frequency signals at point B. The d-c return path for crystal current is provided at the RF end of the mixer assembly by the TR coupling loop and at the IF end by a shunt inductance element located in the grid circuit of the input IF amplifier stage (not shown).

A two-wire equivalent circuit of the mixer is given in figure 11-39 (B). If small losses in the RF line and TR cavity are ignored, the portion of the RF transmission system between antenna and output terminals of the TR cavity may be represented by a signal current source I_s in shunt with the characteristic resistance R_c of the transmission line. Because the local oscillator is loosely coupled to the main line, negligible admittance appears in shunt with the lines A and B in the figure. Elements L1 and C1 represent the RF choke at the IF end of the crystal and are series resonant at the echo signal frequency. Hence, line B is terminated by the crystal at the echo signal frequency. For maximum receiver sensitivity it is important that essentially all the echo power available at the TR device be transferred to the crystal. The

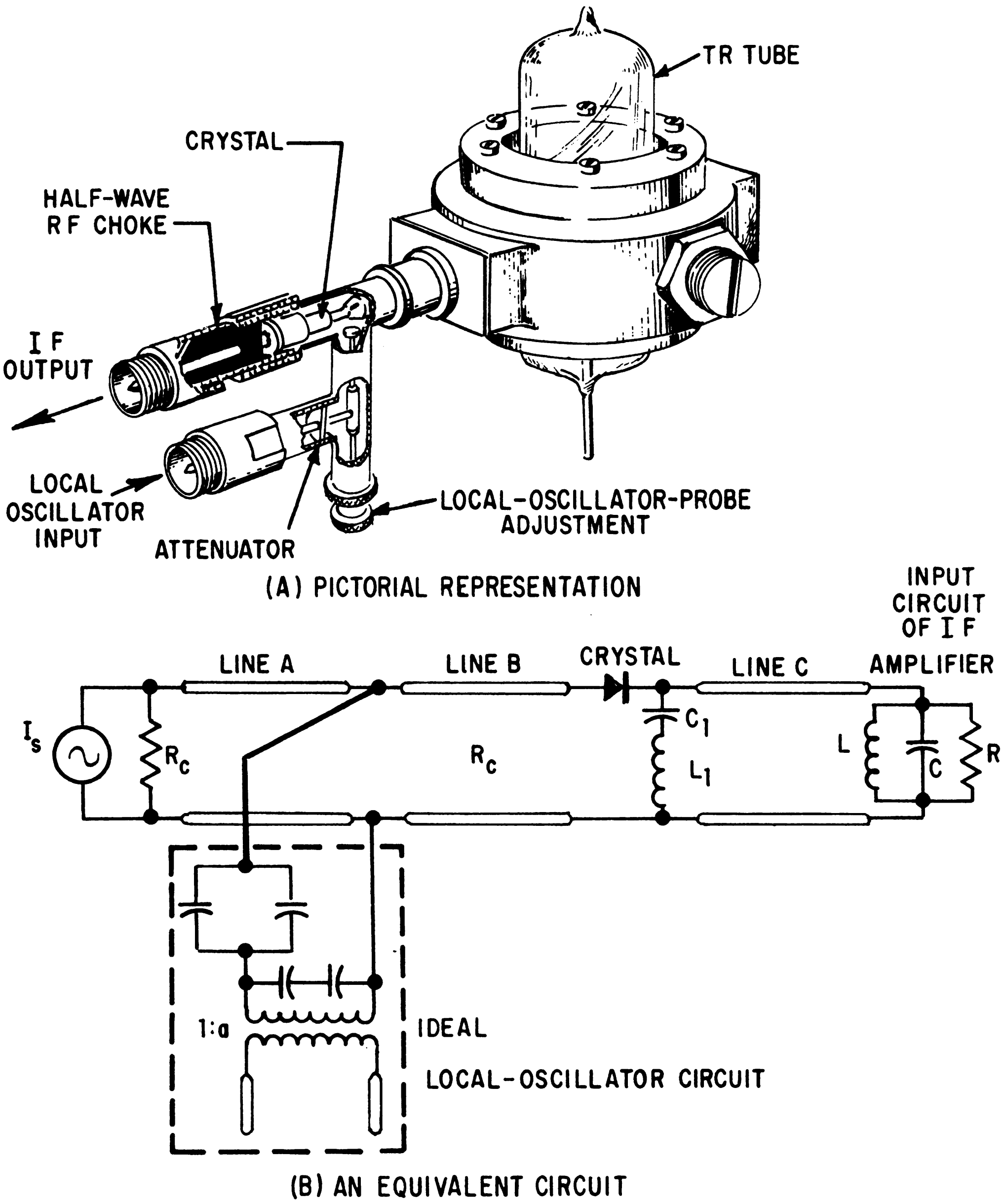
TR TUBE
CRYSTAL
HALF-WAVE RF CHOKE
I F OUTPUT
LOCAL OSCILLATOR INPUT
ATTENUATOR
LOCAL-OSCILLATOR-PROBE ADJUSTMENT
(A) PICTORIAL REPRESENTATION
INPUT CIRCUIT OF I F AMPLIFIER
LINE A
LINE B
CRYSTAL
LINE C
I_s
R_c
R_c
C_1
L_1
L
C
R
1:a
IDEAL LOCAL-OSCILLATOR CIRCUIT
(B) AN EQUIVALENT CIRCUIT

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Figure 11-39.–Single-ended 10-cm coaxial-fed mixer.

crystal should therefore present a matched load termination to the main line section. Fortunately 10-cm crystal units, when operated with 5/16-inch 50-ohm coaxial lines, provide essentially a matched RF load for the line. An impedance changing device between the crystal and the TR cavity is therefore usually unnecessary.

Because the local oscillator is loosely coupled to the main line containing the crystal, an appreciable mismatch of impedance exists on the local oscillator line at the coupling probe. A large impedance mismatch is, in general, undesirable because of the wide variations in the local oscillator load impedance (and hence power output) that result when the oscillator frequency is varied. A good impedance match is particularly important if the line between the local oscillator and the probe is long. To insure a relatively constant load impedance for the oscillator, a resistance disk type of attenuator is often inserted in the local oscillator line, as shown in (A), in order to terminate the line section between the oscillator and the disk in its characteristic resistance. An alternative to the resistance disk is a length of "lossy" cable, which may be inserted between the local oscillator and the mixer assembly. (NOTE: Lossy cable uses resistance wire for the center conductor. An example of lossy cable is RG-21/U.)

Mixer assemblies often include, in addition to the circuit that supplies IF echo signals, a separate mixer for generating IF signals for the automatic frequency control circuit. An example of a 3-cm mixer assembly of this type is shown in figure 11-40. Part (A) is a cutaway pictorial representation; part (B) is an equivalent schematic.

Although this mixer uses two mixing crystals and separate waveguide channels, it is classed as a single-ended mixer because the output signals are independent of each other (due to the use of different signal inputs). Actually, this circuit could be appropriately described as two single-ended mixers.

Local oscillator power and RF echo signals from the TR cavity are coupled into waveguide 1, which serves as the echo signal channel. A crystal extends between the top and bottom walls of the guide, the lower end of the crystal being isolated from the guide by means of a dielectric washer. Echo signal voltages in the IF band appear between the lower end of the crystal and the waveguide, and are conducted to the input circuit of the IF amplifier, usually by coaxial cable.

Waveguide 3 is similar in construction to waveguide 1 and serves as the AFC channel. Power from the local oscillator and a small amount of the transmitter power are applied to the AFC crystal. IF signals for the AFC circuit are derived at the lower end of the crystal mount, as before. Attenuation between the main guide and guide 3 is provided by means of a circular waveguide section operating below cutoff. A disk type attenuator is sometimes included in the circular section to further reduce the amount of transmitter power reaching the mixer assembly.

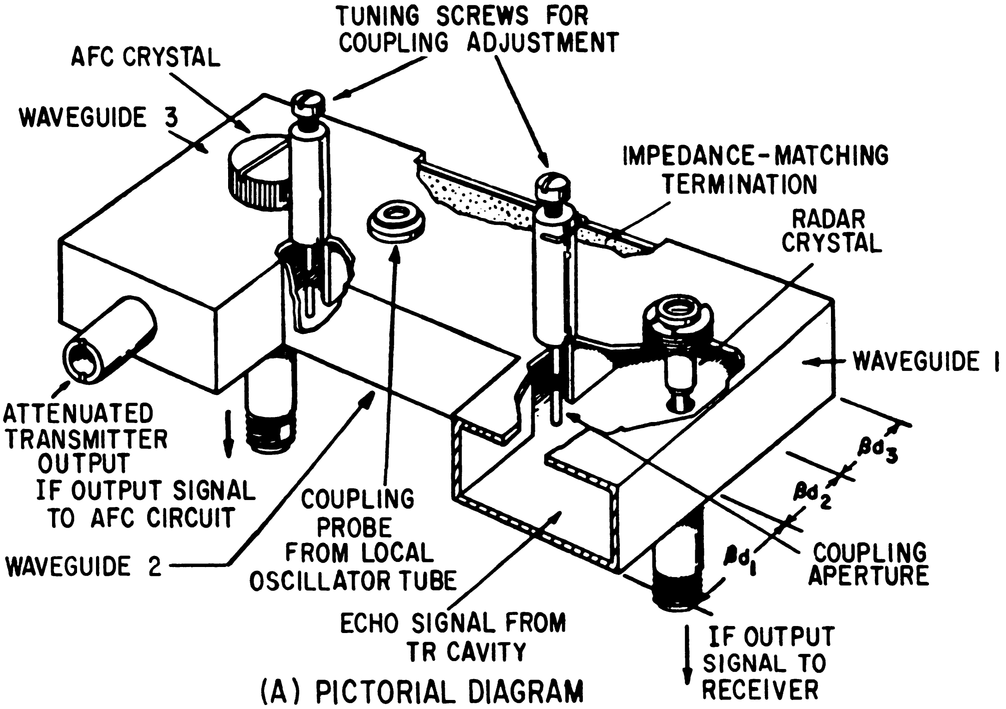
The local oscillator tube is mounted above waveguide 2 in a manner that permits the local oscillator output probe to extend a short distance into guide 2. The coupling probe may be displaced slightly from the center of the transverse axis of the guide. This method is used to obtain a load impedance for the oscillator which provides a reasonably uniform power output over the tuning range.

Local oscillator power is coupled from guide 2 into guides 1 and 3 through coupling apertures located in the side walls of the guides. A matching post and tuning screw extending from the top and bottom walls of the guides at the aperture locations serve to regulate the amount of local oscillator power coupled to the mixer circuits.

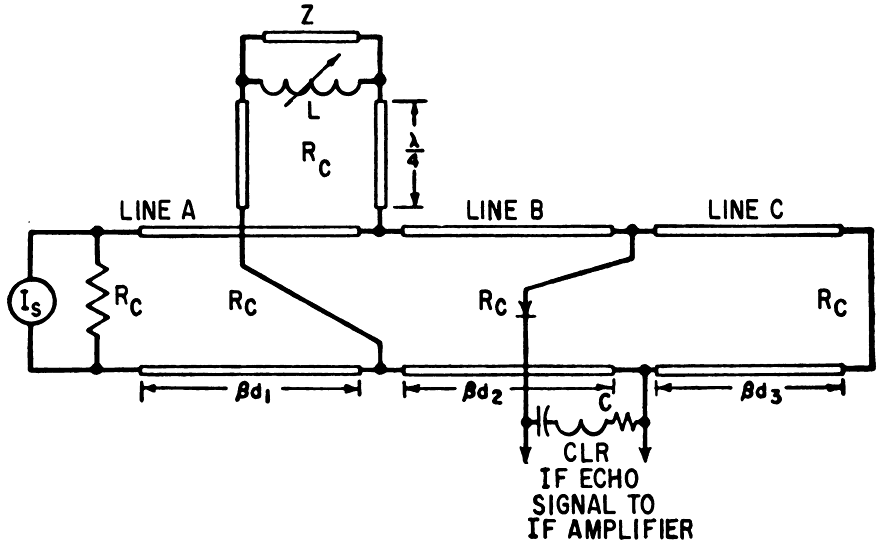
For optimum performance of the radar system, the echo signal channel of the mixer should provide a matched load impedance to the waveguide transmission system. The elements that determine the mixer input impedance are shown in the equivalent circuit (B). The equivalent circuit is derived by dividing waveguide 1 into three sections of lengths (Bd_1, Bd_2, and Bd_3), and representing the sections by equivalent lengths of transmission lines (lines A, B, and C). The signal current generator I_s in shunt with R_c in the equivalent circuit accounts for the portion of the RF system between antenna and mixer. The coupling aperture between the local oscillator and mixer guides (guides 1 and 2) is represented by a variable inductance L, and in shunt with L is an impedance Z which accounts for the impedance seen in the direction of the local oscillator guide. The parallel combination of L and Z terminates a quarter-wave section of line which is in shunt with lines A and B. At the echo signal frequency, the impedance of L and Z in parallel is maintained small enough (in comparison with the characteristic resistance of the quarter-wave line) to make the input impedance of the quarter-wave section extremely high; hence, the amount of echo signal power entering the local oscillator guide is extremely small.

The crystal is located at the junction of lines B and C; across the crystal output terminals is a series RLC circuit. (The counterpart of the RLC combination is an RF choke in the IF output lead of the mixer. The choke prevents RF signals from entering the input circuit of the IF amplifier.)

The length of the shorted-end line C must be such that the input admittance of line C, in shunt with the RF admittance of the crystal, provides essentially a matched load for line B.


TUNING SCREWS FOR COUPLING ADJUSTMENT
AFC CRYSTAL
WAVEGUIDE 3
IMPEDANCE-MATCHING TERMINATION
RADAR CRYSTAL
WAVEGUIDE 1
βd3
βd2
βd1
COUPLING APERTURE
ATTENUATED TRANSMITTER OUTPUT
IF OUTPUT SIGNAL TO AFC CIRCUIT
WAVEGUIDE 2
COUPLING PROBE FROM LOCAL OSCILLATOR TUBE
ECHO SIGNAL FROM TR CAVITY
IF OUTPUT SIGNAL TO RECEIVER

(A) PICTORIAL DIAGRAM



(B) AN RF EQUIVALENT CIRCUIT OF ECHO-SIGNAL CHANNEL

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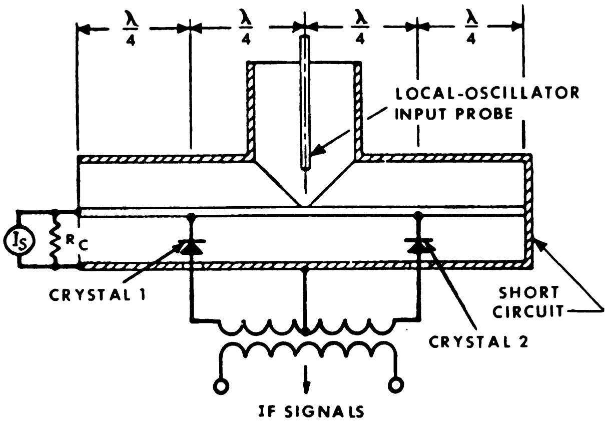
Figure 11-40.—Single-ended 3-cm waveguide-fed mixer.

Varying the length of line C changes the susceptance component of the total admittance at the crystal location. A length of approximately λ/4 is usually preferable in order to minimize changes in admittance with frequency variations.

BALANCED MIXERS.–The noise introduced into the input circuit of a microwave receiver by the local oscillator may be reduced appreciably through use of a balanced mixer. An input circuit of this type employs two crystal mixers connected so that the local oscillator voltages applied to each crystal are in phase and the echo signal voltages at each crystal are phased 180°. This method of circuit connection causes the IF components of local oscillator noise to cancel in the IF amplifier input circuit, and the IF components of the signal to add. Because of their ability to suppress local oscillator noise and because of certain additional advantages to be discussed later, balanced mixers are often preferable to single-ended mixers. They are presently finding wide use in microwave radar systems.

The basic principles of a balanced mixer may be explained from the diagram of figure 11-41, which shows two crystals mounted a half wavelength apart (at the signal frequency) between conductors of a coaxial line section. Each crystal is located a quarter wave from the nearer end of the line, and the local oscillator signal is probe coupled to the line at a point midway between the crystals. The output terminals of the crystals are connected to an IF transformer, the primary winding of which is balanced to ground. The signal current generator I_S in shunt with resistance R_C accounts for signals entering the mixer from the TR device.



AT.222

Figure 11-41.–Coaxial line balanced mixer circuit.

The local oscillator coupling probe gives rise to two waves traveling in opposite directions in the coaxial line. Assume that the local oscillator frequency at the TR device presents a short circuit to the local oscillator wave traveling to the left, and that the crystals have identical RF impedances equal to twice the characteristic resistance of the line. Then equal-amplitude, in-phase, local oscillator voltages appear at the crystals. Because of the half-wave spacing between crystals, the RF echo signal voltages at the crystals are also of equal amplitude but are 180° apart in phase. An in-phase relation between the local oscillator and echo signal voltages produces an IF signal voltage of one phase, and a 180° phase relation between the local oscillator and echo signal produces an IF signal voltage of opposite phase. Thus the two IF echo signal voltages add in the balanced input circuit of the IF amplifier. Because the noise that accompanies the local oscillator signal produces voltage components that bear the same phase relation to the local oscillator voltage at each crystal, the corresponding IF components of noise at the output of each crystal are in phase, cancel, and hence produce no resultant noise voltage across the IF transformer.

In order to realize full benefit from use of a balanced mixer circuit, the crystal should have similar RF impedance as assumed above, and in addition they should have similar conversion gains. Under these conditions of operation, only one-half the available RF power is applied to each crystal; but since the power in the IF signals from the two crystals add together, the total IF power is the same as that obtained from a single-ended mixer. Since IF components of the local oscillator noise are completely eliminated, maximum reduction in overall noise figure is obtained.

An imbalance in conversion gain yields an imbalance in the IF signal voltages obtained from the crystals, and also an imbalance in the IF components of local oscillator noise voltages at the crystal output terminals. However, since the IF signal voltages are additive and the local oscillator noise components are subtractive, small imbalances in conversion gain do not seriously affect the overall receiver noise figure.

More important are the effects of a difference in the RF admittances of the crystals. An imbalance of this type causes both the echo signal power and the local oscillator power to divide unequally between the two crystals. As a result, the IF signal power obtained from the mixer is appreciably reduced, and the IF components of local oscillator noise are prevented from canceling completely. Crystals intended for use in this type of mixer must be carefully selected on the basis of equal RF admittance in order to insure most satisfactory operation.

MICROWAVE FERRITES

The most common ferromagnetic substances (iron, nickel, cobalt, and their alloys) are good electrical conductors. They cannot, therefore, be used as magnetic materials at the higher frequencies because of eddy current losses. Ferrites, however, are not subject to eddy currents. Even though their magnetic susceptibility is much lower than that of the ordinary ferromagnetic substances, they can be used at the higher frequencies. Ferrites are unique because they have useful magnetic properties and are also insulators. RF fields can penetrate a ferrite; this is not possible in a conducting magnetic substance.

At microwave frequencies, the greatest use of ferrites is in nonreciprocal propagation devices. Nonreciprocal devices can be used to isolate a signal source from its load. A magnetron or other microwave signal source operating into a varying mismatched load (as in the case of a scanning antenna which is fed by a line with rotating joints;) tends to "pull" in frequency. If the reflected energy caused by mismatch is absorbed or diverted before it reaches the source, the source will "see" a constant load.

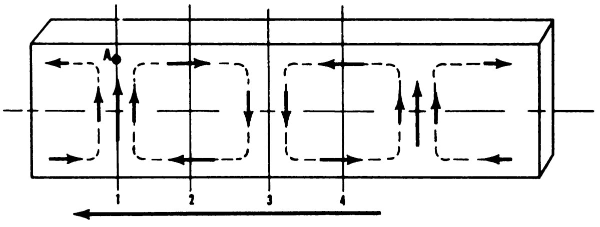
Nonreciprocal ferrite devices make use of the interaction of the electron's spin with an external magnetic field.

Ferromagnetic Resonance

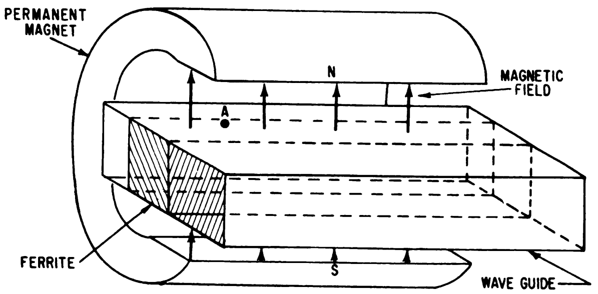
When a ferrite is placed in an external magnetic field, the "atomic" magnets within the ferrite tend to line up with the external field. A spinning electron has gyroscopic properties. When an external force attempts to change the spin axis, the electron precesses. Any gyro has a preferred or natural precession frequency which is proportional to the strength of the external field. By proper choice of ferrite material and external field strength, the natural precession frequency can be made to coincide with any selected microwave frequency.

An electromagnetic wave traveling down a waveguide will produce, at a point off the centerline of the guide, a rotating magnetic field. This is illustrated in figure 11-42(A). As the wave advances from right to left, the stationary point A sees a clockwise rotating magnetic field. A wave traveling from left to right will produce, at point A, a magnetic field with counterclockwise rotation.

A slab of ferrite placed off center in a waveguide, as shown in (B), will act as a one-way device at a frequency which depends on the external magnetic field strength. If the ferrite's preferred electron precession frequency matches the frequency of an RF wave traveling from left to right in the guide, the ferrite will absorb most of the energy in the wave; the rotating magnetic field as seen at point A will aid electron precession. The electrons will



(A) MAGNETIC FIELD ROTATION



(B) RESONANCE ISOLATOR

AT.223

Figure 11-42.—Ferromagnetic resonance.

precess vigorously and convert the RF energy to heat. This phenomenon is known as ferromagnetic resonance. A wave traveling from right to left will be attenuated very little because its rotating magnetic field will oppose electron precession. The one-way device shown is a RESONANCE ISOLATOR.

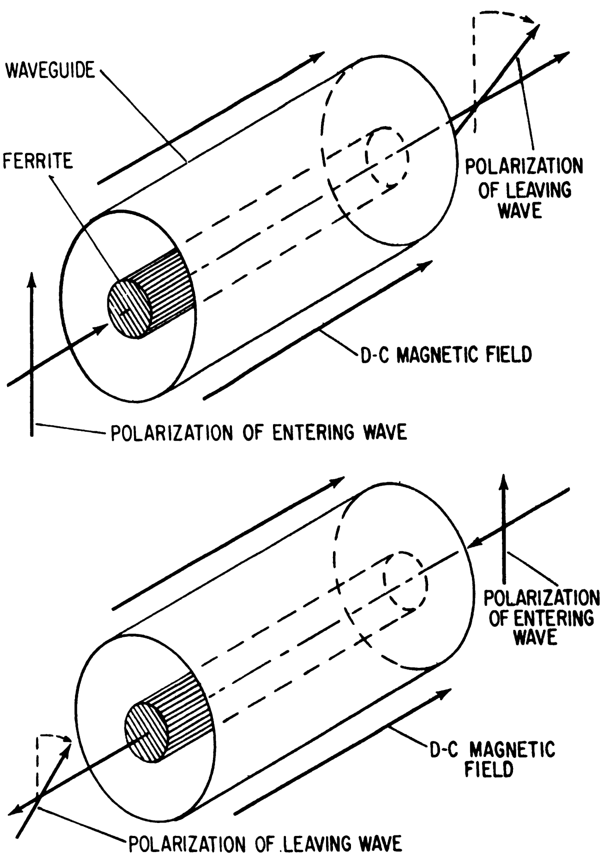
Faraday Rotation

If a plane-polarized wave is propagated through a circular (or square) waveguide containing an axially mounted ferrite rod, the plane of polarization will be rotated when a magnetic field is applied parallel to the direction of propagation. The amount of rotation will depend on the strength of the applied field and the dimensions of the ferrite rod. The sense or direction of rotation will depend only on the polarity of the magnetic field. Figure 11-43 illustrates Faraday rotation.

Faraday rotation occurs as the wave travels past the ferrite rod. The plane of rotation is shifted in the same direction, regardless of the direction of wave propagation, as can be seen by comparing (A) and (B) of the figure.

An isolator which uses the Faraday effect is shown in figure 11-44 (A) and (B). A plane-polarized wave comes down the guide and goes through a rectangular-to-round waveguide transition. As the wave passes the ferrite in (A), its plane of polarization is rotated 45° clockwise, and it leaves through the rectangular guide. If a wave comes down the guide in the reverse direction, it will also be rotated 45° clockwise (as viewed from the left) as shown in (B). The wave will be 90° from the transmission plane of the rectangular guide (the guide will be cut off for this polarization), and the wave will be reflected. Properly oriented vane type absorbers will absorb this energy without affecting waves traveling in the other direction.

In isolators designed to handle high power, the reflected wave can be coupled out to a separate power-absorbing load. An isolator of this type is shown in figure 11-44 (C).


WAVEGUIDE
FERRITE
POLARIZATION OF LEAVING WAVE
D-C MAGNETIC FIELD
POLARIZATION OF ENTERING WAVE
POLARIZATION OF ENTERING WAVE
D-C MAGNETIC FIELD
POLARIZATION OF LEAVING WAVE

AT.224

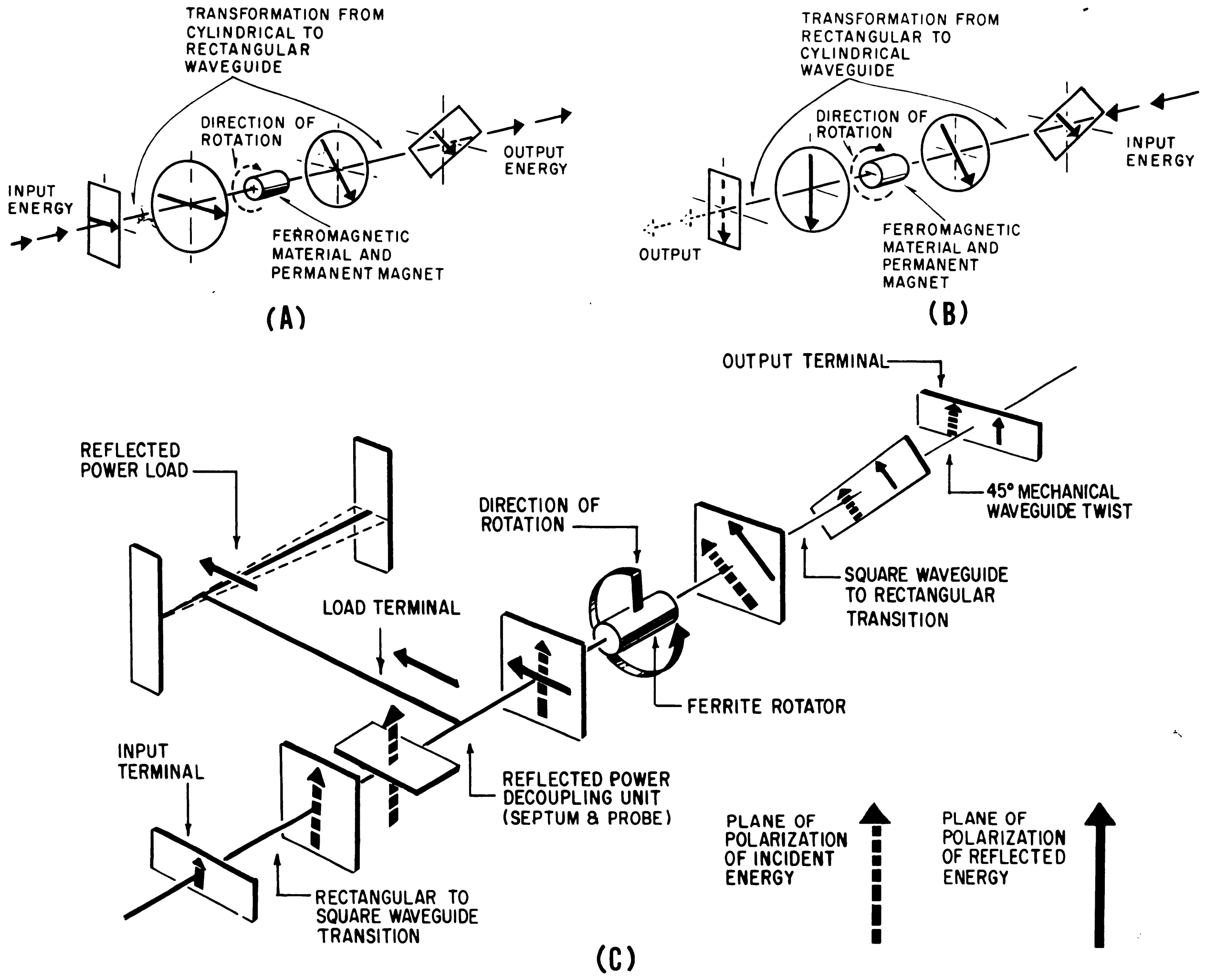
Figure 11-43.–Faraday rotation.

Switches

A Faraday isolator can be modified to act as a single pole, double throw, WAVEGUIDE SWITCH. In the waveguide switch, the output end of the device has two rectangular output guides 90° apart. Each output guide is 45° from the input guide at the other end of the device. An electromagnet supplies the external field. Switching is accomplished by reversing the direction of current flow in the electromagnet. Current in one direction causes the RF wave polarization to be rotated clockwise 45°. Electromagnetic current in the opposite direction causes the wave polarization to rotate 45° counterclockwise. In each case, only one of the output guides will accept the RF wave. Switching times of less than 1μsec are possible. Isolation between the output guides (if they are properly terminated) is on the order of 40 db. This type of switch can be used to switch a transmitter between two antennas.

Circulators

A CIRCULATOR is a device which allows one-way propagation of signals through it. It


TRANSFORMATION FROM CYLINDRICAL TO RECTANGULAR WAVEGUIDE
DIRECTION OF ROTATION
OUTPUT ENERGY
INPUT ENERGY
FERROMAGNETIC MATERIAL AND PERMANENT MAGNET
(A)
TRANSFORMATION FROM RECTANGULAR TO CYLINDRICAL WAVEGUIDE
DIRECTION OF ROTATION
INPUT ENERGY
OUTPUT
FERROMAGNETIC MATERIAL AND PERMANENT MAGNET
(B)
OUTPUT TERMINAL
REFLECTED POWER LOAD
45° MECHANICAL WAVEGUIDE TWIST
DIRECTION OF ROTATION
SQUARE WAVEGUIDE TO RECTANGULAR TRANSITION
LOAD TERMINAL
FERRITE ROTATOR
INPUT TERMINAL
REFLECTED POWER DECOUPLING UNIT (SEPTUM & PROBE)
PLANE OF POLARIZATION OF INCIDENT ENERGY
PLANE OF POLARIZATION OF REFLECTED ENERGY
RECTANGULAR TO SQUARE WAVEGUIDE TRANSITION
(C)

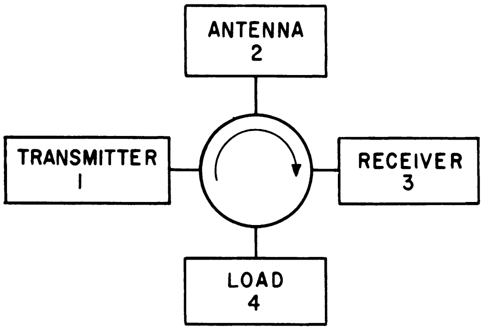
AT.225

Figure 11-44.–Faraday isolators.

may have several input-output ports. Figure 11-45 is a schematic of a four-port circulator. The arrow shows direction of power flow within the circulator. Power entering port 1 leaves by port 2 only; power entering port 2 leaves by port 3 only, etc. This one-way power flow between ports results from rotation of the signal polarization between ports. Each port is so oriented that it will be cut off for all signals except those which entered the port just before it. Each port, if it is properly terminated, will accept all of the power from the preceding port. A four-port circulator may be used as a radar duplexer. The load at port four absorbs any local oscillator signal from the receiver and prevents it from being radiated.

ANTENNAS

An antenna is a special type of electrical circuit intentionally designed to radiate and/or receive electromagnetic energy. In an ordinary circuit, the inductance, capacitance, and resistance are lumped constants and therefore the electromagnetic field is confined to the circuit where it performs useful work. In an antenna, the L, C, and R properties are distributed and the electromagnetic field is not confined–it is spread



AT.226

Figure 11-45.–Circulator.

out and tends to escape or radiate. It is this radiated field which provides the link between a transmitter and receiver.

The method of propagation is of interest, but of more concern to the technician is how the energy can be directed (the radiation pattern) and concentrated (the beamwidth), and how the efficiency (gain) can be enhanced. A familiarity with the basic types of antenna systems and the polarization of the transmitted wave provides a background of information and an appreciation of the problems involved in the selection of a suitable antenna type for a specific application.

Several of the more common antenna configurations with typical operating frequency ranges and radiation patterns are shown in figures 11-46 and 11-47. These figures should be consulted throughout the discussions which follow. Table 11-2 lists the normal polarization and directional characteristics of certain antenna types.

While the simplest type of antenna is the bidirectional dipole, limitations in directivity, frequency passband, and gain somewhat restrict its use. Other dipole configurations such as the ram's horn and the corner reflector are used for special applications.

Although the crossed dipole, the whip, the top-loaded vertical, or the "J" is sometimes used, the ground plane antenna is probably the most popular when reception or transmission

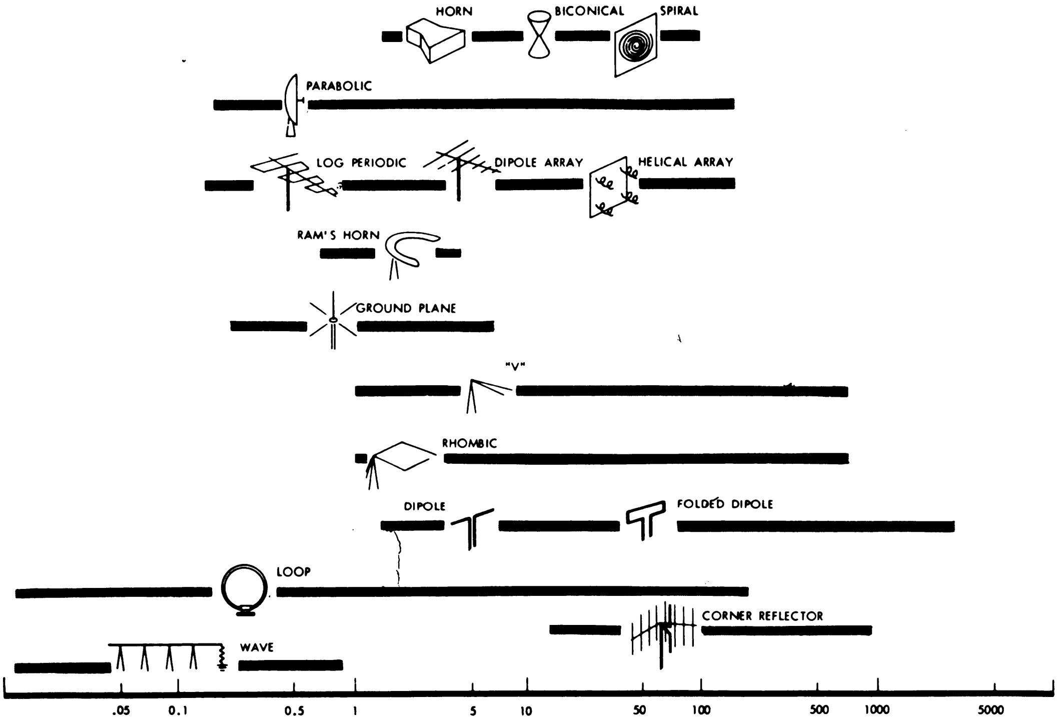


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Figure 11-46.–Antenna selection based on typical operating frequencies in megahertz.

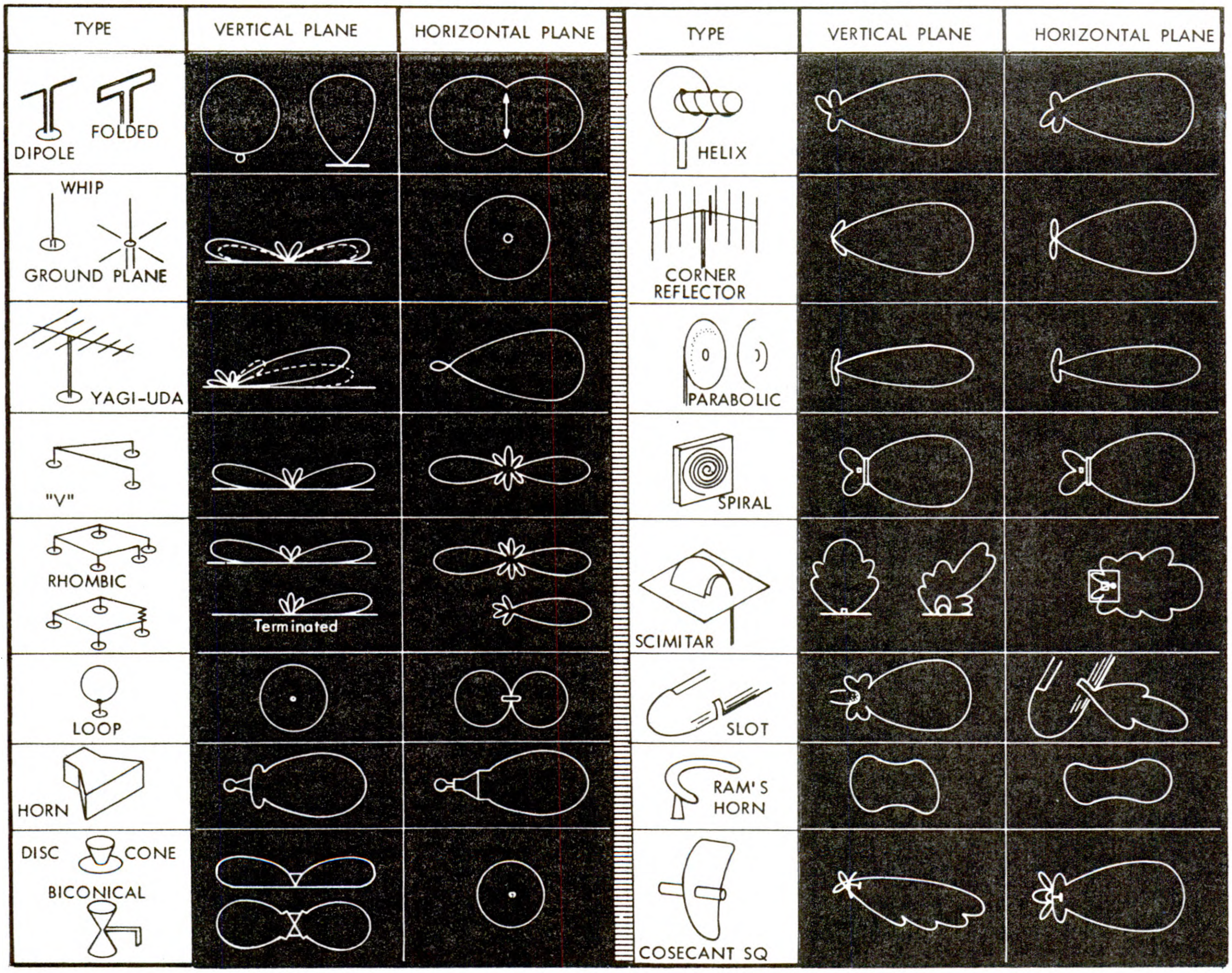

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Figure 11-47.—Typical radiation patterns for selected types of antennas.

must be equally effective in all directions (omnidirectional). For much higher frequencies, the biconical or the disk horn is recommended.

The log periodic, helical, and flat-spiral antennas are noted for their extremely wide (as high as 20:1) operating frequency range.

When space is not a controlling factor, the rhombic and the "V" type are often used to provide high gain and directivity. Both types normally are bidirectional. The rhombic can be made unidirectional by terminating the ends of the legs with a noninductive resistor. The "V" is made unidirectional by the use of another "V" spaced an odd number of quarter wavelengths behind the original. Typical legs for the rhombic are three to four wavelengths; for the "V" type, legs of eight wavelengths are not uncommon.

The parabolic antenna is capable of producing high gain and excellent directivity. Although screen mesh or even a grid or rods may be used where wind resistance is a design factor, the reflector element generally consists of a solid surface. Physically the reflector should be several wavelengths in diameter. Additional gain also can be obtained by mounting a hemispherical reflector in front of the dipole, provided its surface area does not appreciably shadow the rear parabolic reflector. The radiating element may be a dipole, a horn, or other suitable radiator.

Table 11-2.—Antenna characteristics.

Type	Usual polarization	Directivity
Dipole	Horizontal	Bidirectional
Dipole array	Horizontal	Unidirectional
Ground plane	Vertical	Omnidirectional
Parabolic	Horizontal	Unidirectional
Horn	Horizontal	Unidirectional
Corner reflector	Vertical	Unidirectional
Helical array	Circular	Unidirectional
Ram's horn	Horizontal	Bidirectional
Rhombic	Horizontal	Bidirectional, unidirectional
Log periodic	Horizontal	Unidirectional
Spiral	Circular	Bidirectional
Loop	Horizontal	Bidirectional
Biconical	Horizontal	Omnidirectional

CHAPTER 12

SERVOSYSTEMS

There are many types of servosystems in use, such as electronic, hydraulic, and amplidyne. There are also many different variations and combinations of these basic types. It is beyond the scope of this training manual to describe all systems in detail, since each servosystem is designed for a specific task. Therefore for each specific system the applicable manual should be referenced.

It is recommended that the basic theory of synchros and servomechanisms as discussed in Basic Electricity, NavPers 10086-B be reviewed before proceeding in this manual.

BASIC TYPES OF CONTROL

A servomechanism, in carrying out its orders, accomplishes its task by exercising control over a source of power. Control implies the conditional use of an external source of power, which in most cases is substantially greater than the controlling power. Almost unlimited quantities of mechanical or electrical power can be controlled by opening or closing a simple valve or switch.

Since a servomechanism is a device for exercising control of some external source of power, it is well to consider the various basic types of controls and their characteristics. A control system may encompass the control of electrical, mechanical, hydraulic, pneumatic, or thermal units, or of various combinations of different units.

The simplest form of control can be illustrated by the elementary electric circuit shown in (A) of figure 12-1. The circuit contains a source of power; a switch, or controlling device; and a load consisting of a heater element. The components are connected in series; and when the switch is closed, energy flows to the load and performs useful work; when the switch is opened, the energy source is disconnected from the load. Thus, the flow of energy is either zero or a finite value determined by the resistance of the circuit. Operation of this general type is called discontinuous control.

In (B) of figure 12-1 the circuit shown is modified by substitution of a rheostat for the switch; and the circuit now provides continuous control. By displacing the rheostat contact, the circuit resistance is varied continuously over a limited range of values. The energy expended in the load is then varied or regulated over a corresponding range rather than by intermittent, or on-off, action as in discontinuous control. These examples represent a fundamental property of control systems in general; the energy required to control the system is small compared with the quantity delivered to the load.

As discussed above, the power source is controlled directly by the manual adjustment of a switch or of a rheostat. In more complicated systems, control signals are applied to the power device by the action of an automatic electrical or mechanical device rather than by manual means. The device which develops the control signals is called an automatic controller, and the entire system is known as an automatic control system.

Automatic control systems can be divided into two basic types: open-loop and closed-loop systems. An example of an automatic open-loop control system is an electric timer used to control the action of the heating element. (See fig. 12-1 (C).) Although the heater is switched on and off automatically, the temperature of the oven in no way affects the switching action of the timer. The initiating action (timer) is independent of the results obtained.

If a bimetallic spring type thermostat is substituted for the switch as shown in figure 12-2, the temperature of the oven will control the power applied to the heater. When the temperature rises to a predetermined level, the thermostat will open the circuit. When the temperature falls slightly below this point, the spring cools, closing the contacts, and the heater again begins operation. The controlling device is affected by the results of the load and is known as a closed-loop system.

All controls described are used to regulate the power to the heater. Thus, they may be classified as regulating controls. An example of their application in electronic equipment may be found in the regulation of pressure, temperature, and speed.

Another type of control is the positioning control. As the name implies, the positioning control is used to position a shaft or some other form of load. The basic fundamentals applicable to regulating controls also apply to positioning controls. Thus, positioning controls may be continuous or discontinuous, open-loop or closed-loop, and manual or automatic. However, most controls with which the technician is concerned are of the continuous, automatic, closed-loop type.

To insure a thorough understanding of this type of control, briefly review what it encompasses. A block diagram of such a system is shown in figure 12-3. An order is issued by the

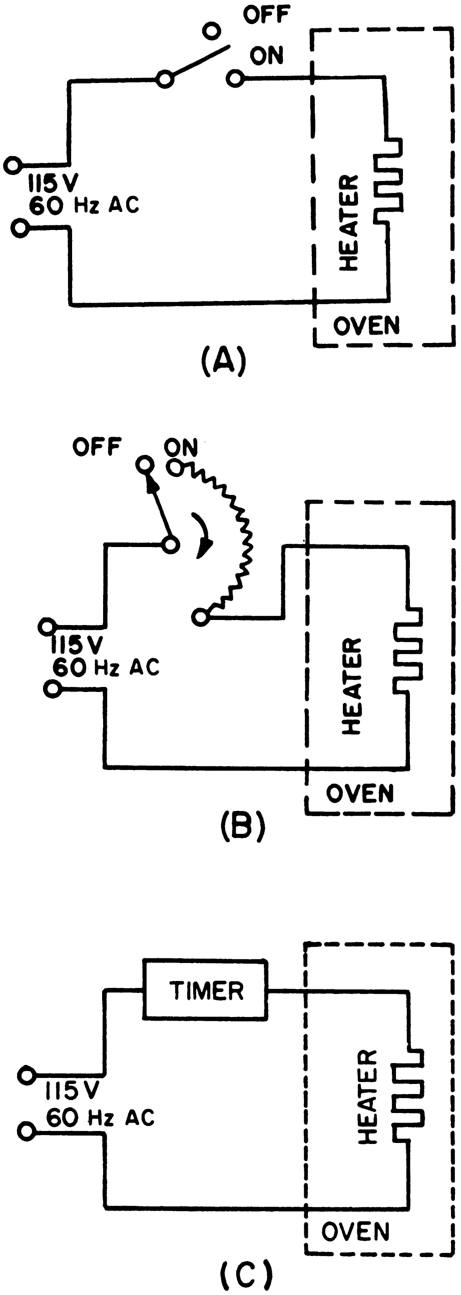

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Figure 12-1.—(A) Discontinuous control; (B) continuous control; (C) automatic control.

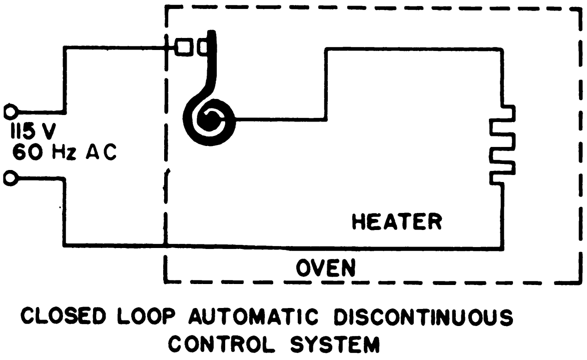

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Figure 12-2.—Closed-loop, automatic discontinuous control system.

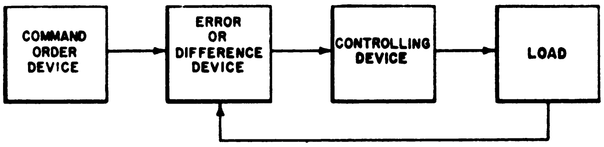

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Figure 12-3.–Block diagram showing continuous, automatic, closed-loop type of control system.

command order device to change the position of the load to a certain location. The error or difference measuring device receives the order, compares it with the present position of the load, and issues an order to the controlling device based on the difference between the ordered location and present location. This is a continuous process until the load reaches the ordered position.

A type of automatic closed-loop positioning control system frequently used in aviation electronic equipment is the servomechanism. A servomechanism may be defined as a feedback automatic control system that measures the output, compares it with the input, and uses the resulting error signal to control comparatively large amounts of load power.

BASIC SERVOMECHANISMS

The essential components of a servomechanism are the data transmission system, the servocontrol amplifier, and the servomotor. These components are shown in the block diagram of figure 12-4 and are discussed in the following paragraphs.

The functions of the data transmission system are as follows:

1. To measure the servo output.
2. To transmit or feed back the signal, which is proportional to the output, to the error detector (a differential device for comparing two signals).
3. To compare the input signal with the feedback signal to the servo.
4. To transmit to the servoamplifier a signal which is proportional to the difference between the input and output signals.

The signal obtained by comparing the servo input and output is called the servo error, and is represented by the sumbol E. Figure 12-4 shows that the servo error (E) is the difference between the input (θ_i) and the output (θ_o). This is stated mathematically as $E = \theta_i - \theta_o$.

In many servosystems the physical location of the servo input device and output device are remotely located from each other and may also be remotely located from the servoamplifier. This requires some means of transmitting the output information back to the device receiving the input command. This transmission system as well as the comparing device (called an error detector) is part of the data transmission system.

The function of the servoamplifier is to receive the error signal from the error detector, amplify it sufficiently to cause the output device to position the servo load to the commanded position, and to transmit the amplified signal to the servomotor.

The servomotor functions to position the servo load. The motor must be capable of positioning the load so as to require a minimum response time based on the requirements of the system.

ERROR DETECTORS

The component of the data transmission system that compares the input with the servomechanism output is the error detector. An error detector can be either a mechanical or an electrical device. A simple form of a mechanical error detector is the differential. However, most error detectors are electrical devices because of their adaptability to widely separated or remotely installed components. Most of the electrical devices used are of either the potentiometer (resistive) or one of several magnetic devices.

Electrical error detectors may be either a-c or d-c devices depending upon the requirements of the servosystem. An a-c device used as an error detector must compare the two input signals and produce an error signal of which the phase and amplitude will indicate both direction and amount of control necessary for correspondence. A d-c device differs in that the polarity of output error signal determines direction of the correction necessary.

Error detectors are also used extensively in gyro stabilized platforms and rate gyros. In

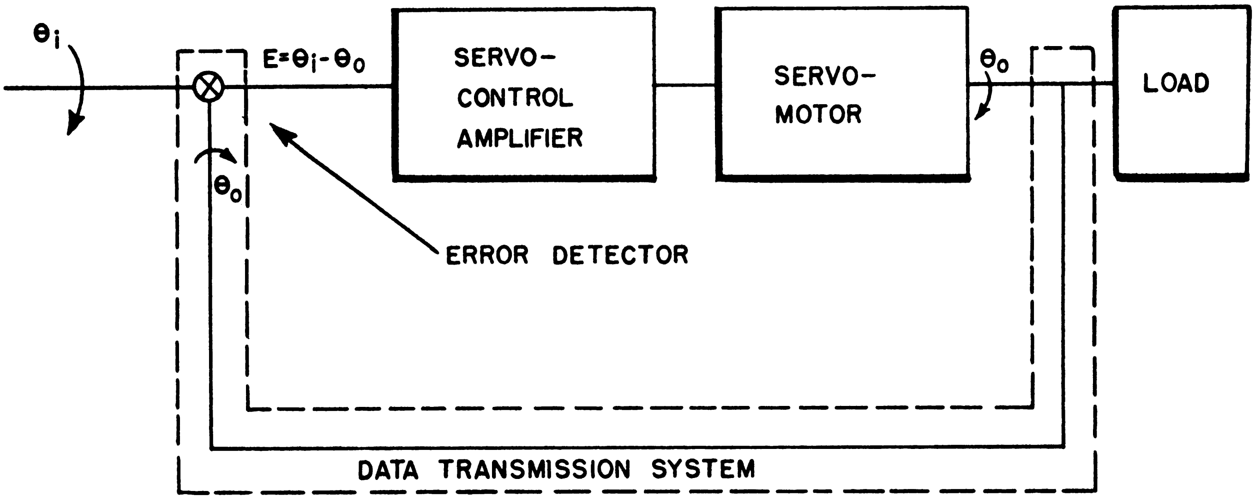

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Figure 12-4.—Simplified block diagram of a servomechanism.

the stabilized platform, synchros are attached to the gimbals. Thus, any movement of the platform around the gyro axes is detected by the synchro and the error voltage is sent to the appropriate servosystem.

In rate gyros, the E-transformer (discussed later) is commonly used to detect gyro precession. It is extremely sensitive to very slight changes, but its movement is limited to a very small amount. Thus, it is extensively used with constrained gyros.

POTENTIOMETER

Potentiometer error detector systems are generally used only where the input and output of the servomechanism has limited motion. They are characterized by high accuracy, small size, and the fact that a d-c or an a-c voltage may be obtained as the output. Their disadvantages include limited motion, a life problem resulting from the wear of the brush on the potentiometer wire, and the fact that the voltage output of the potentiometer changes in discrete steps as the brush moves from wire to wire. A further disadvantage of some potentiometers is the high drive torque required to rotate the wiper contact.

An example of a balanced potentiometer error detector is shown in figure 12-5. As stated above, the purpose of the circuit is to give an output error voltage which is proportional to the difference between the input and output signals.

The command input shaft is mechanically linked to R1 and the load is mechanically linked to R2. An electrical source of 115 volts a.c. is applied across both potentiometers.

When the input and output shafts are in the same angular position, they are in correspondence and there is no output error voltage. If the input shaft is rotated, moving the wiper contact of R1, an error voltage is applied to the control amplifier. This error voltage is the difference of the voltages at the wiper contacts of R1 and R2. The output of the amplifier causes the motor to rotate the load and the wiper contact of R2 until both voltages are equal; thus, there is no output error voltage.

Figure 12-5 illustrates R1 and R2 grouped together. In actual practice the potentiometers may be positioned remotely from each other, with R2, the output potentiometer, being located at the output shaft or load. This remote location of one of the components does not remove it from being a part of the error detector.

E-TRANSFORMER

A type of magnetic device which is used as an error detector is the E-transformer. Its application is useful in systems that do not require the error detector to move through large angles. A simplified drawing, which is one of several possible devices in this category, is shown in figure 12-6.

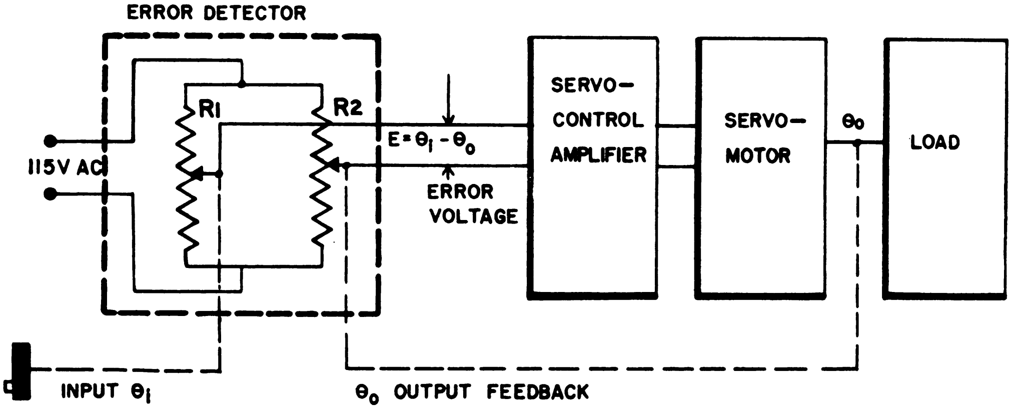

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Figure 12-5.–Balanced potentiometer error detector system.

The primary excitation voltage is applied to coil A on the center leg of the laminated core. The coupling between coil A and the secondary windings, coils B and C, is controlled by the armature which is displaced linearly by the input signal. At the position of the armature where the coupling between the windings is balanced, the output voltage is minimum because of the series-opposing connections of the secondary windings. The phase of the output voltage on either side of the voltage null differs by 180°, and by proper design of the transformer the amplitude can be made proportional to the displacement of the armature from its null voltage position. This type of error detector possesses the advantages of small size and high accuracy, but has the disadvantage of permitting only limited input motion.

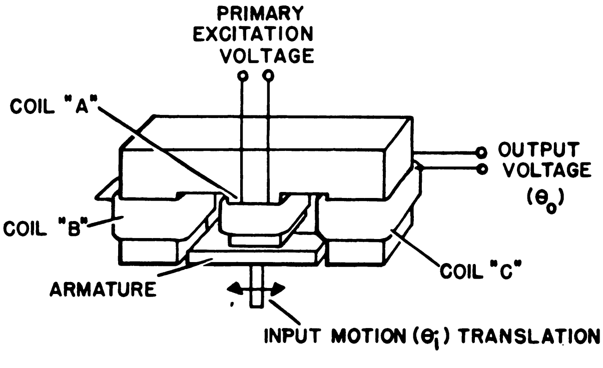

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Figure 12-6.–E-transformer error detector.

CONTROL TRANSFORMER

Synchros have been developed to a point of relatively high accuracy, low noise level, reasonably small driving torques, and excellent life. These qualities are also applicable to the synchro control transformer. A primary advantage over other types of error detectors is its unlimited rotation angle; that is, both the input and the output to the synchro control transformer may rotate through unlimited angles. Among the disadvantages of synchros (including the synchro control transformer) are the large size necessary to maintain high accuracy, the power consumed, and the fact that the output supplied to the servocontrol amplifier is always a-c modulated with the servo error and must be demodulated in the servocontrol amplifier if it is to be applied to a d-c servomotor.

The synchro data transmission system is comprised of a synchro transmitter, a synchro control transformer, and in some cases a differential transmitter for additional servo inputs. The synchro transmitter transforms the motion of its shaft into electrical signals suitable for transmission to the synchro control transformer, which comprises the error detector. (See fig. 12-7.)

The stator of the transmitter consists of three coils spaced 120 electrical degrees apart.

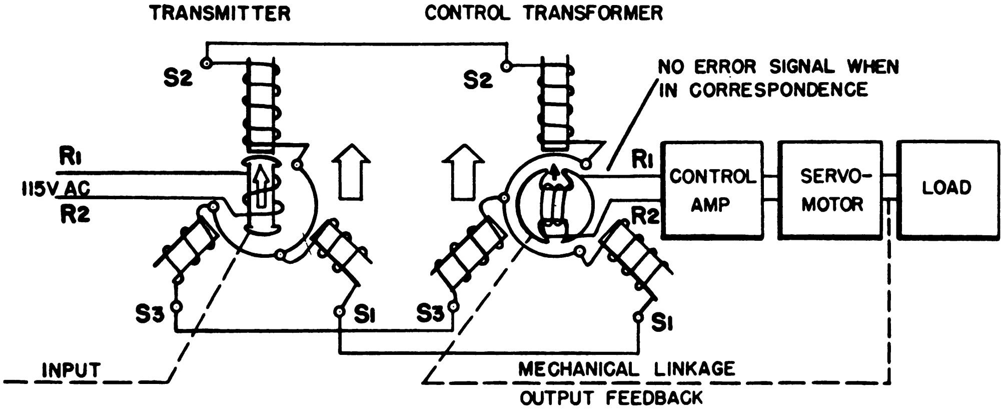

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Figure 12-7.–The control transformer as an error detector.

The voltage induced into the stator windings is a function of the transmitter rotor position. These voltages are applied to the three similar stator windings of the synchro control transformer. The voltage induced in the rotor of the synchro control transformer depends upon the relative position of this rotor with respect to the direction of the stator flux.

The variation of the synchro control transformer output voltage as a function of the rotor position relative to an assumed stator flux direction is shown in figure 12-8. While there are two positions of the rotor, 180° apart, where the output voltage is zero, only one corresponds to a stable operating position of the servo.

In cases where a synchro differential transmitter is used for additional inputs to the servosystem, it is connected between the synchro transmitter and the synchro control transformer. (See fig. 12-9.) When the synchro differential rotor is in line with its stator windings, the differential transmitter acts as a one-to-one ratio transformer and the voltages applied to the synchro control transformer are the same as the voltages from the synchro transmitter. If the synchro differential transmitter rotor is displaced by a second input, the voltages from the synchro transmitter to the control transformer are modified by the synchro differential transmitter by the amount and direction of its rotor displacement. Thus, the two inputs are algebraically added and fed to the synchro control transformer as a single input. Where a synchro differential is used as a receiver, the rotor shaft indicates the angular sum or difference between two transmitter positions.

Magnetic error detectors are not limited to E-transformers and synchro devices as other types may be encountered in equipment where special requirements must be met.

MULTIPLE-SPEED DATA TRANSMISSION SYSTEMS

The static accuracy of a servomechanism is frequently limited only by the accuracy of the data transmission system. The accuracy of the data transmission system may be increased considerably by employing a multiple-speed data transmission system along with the single-speed system. The error-detector elements of the multiple-speed transmission system rotate at some multiple of the shaft being controlled, while the elements of the single-speed transmission system operate one to one with respect to the controlled shaft.

The schematic diagram of a multiple- and single-speed system is shown in figure 12-10. If the input shaft turns through 1° in this example, the single-speed synchro transmitter also is rotated 1° while the multiple-speed unit is rotated 10°. The synchro control transformer associated with each of these transmitters is geared in similar ratios with respect to the servo output shaft. A 1° error between the position of the input and outputs shafts therefore produces a relative rotor displacement of 1° in the single-speed synchros and 10° in the multiple-

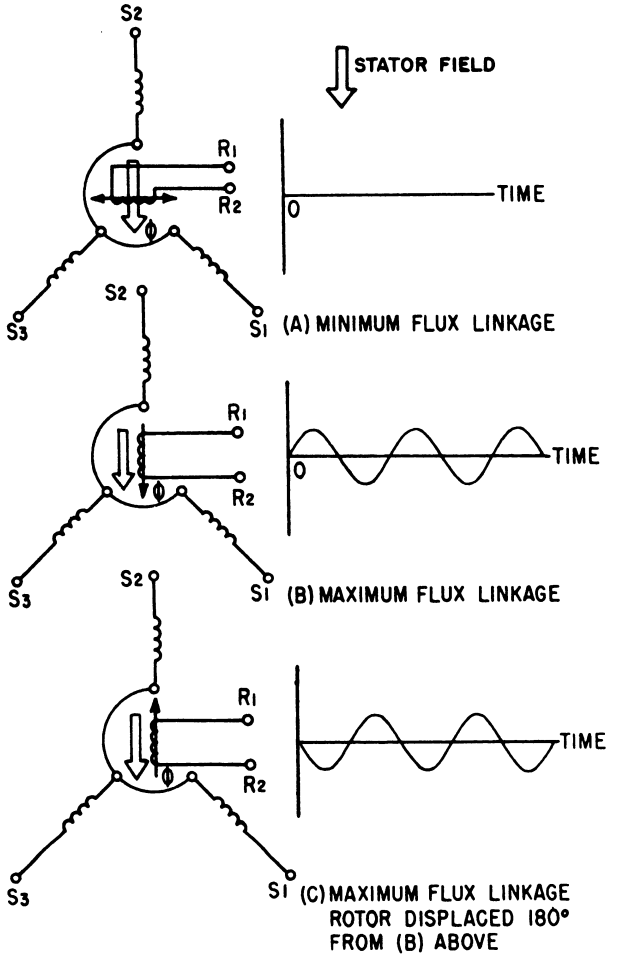

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Figure 12-8.—Induced voltage in synchro control transformer rotor.

speed synchros. If the relation between the rotor displacement and output voltage is linear, the error signal from the multiple-speed system is 10 times that from the single-speed system. This amplification of the error signal in the data transmission link reduces the signal amplification required in the servocontroller. If the synchro has an inherent error of 0.1° with respect to its own shaft, the consequent servo error introduced by a single-speed data transmission system will be of corresponding magnitude, but the consequent servo error introduced by a 10-speed data transmission system will be only one tenth as great, or 0.01°.

A disadvantage of using a multiple-speed error detector lies in the possibility of the system falling out of step and synchronizing in a position differing from the correct position by an integral number of revolutions of the multiple-speed synchro. In the example shown in figure 12-10, if the output shaft were held fixed and the input shaft rotated 36°, the 10-speed synchro transmitter would turn one complete revolution. At this point the error signal from the multiple speed error detector would be zero. If the output shaft were then released, the system would operate in a stable fashion with a 36° error between the input and output shafts. The purpose of using a single-speed error detector along with the multiple-speed detector is to prevent this ambiguous synchronization.

An error signal selector circuit is provided which switches control of the servo to the single-speed data transmission system whenever the servo error becomes large enough to permit the multiple-speed system to synchronize falsely.

The simplest device imaginable that could control an error-selector circuit is shown in figure 12-10. It is essentially a single-pole, double-throw relay actuated by the output of the single-speed error detector. The relay is shown in the deenergized position. When the output of the single-speed synchro is high, the relay is energized and the single-speed circuit controls the servomotor. When the output is low, the relay opens and the 10-speed synchro controls the circuit. Keep in mind that the synchro output is high only when there is a large error.

The relationship of the coarse (single-speed) synchro output and the fine (10-speed) synchro output is shown in figure 12-11 (A). The shaded portion represents the area where control can be switched from single-speed circuit to the 10-speed circuit. With the selector circuit shown it is still possible to have a single ambiguous synchronizing point. This point is at the 180° position of the single-speed (coarse) synchro. At this point the single-speed (coarse) and 10-speed (fine) shafts are nulled (but are 180° out of phase) and control is switched to the 10-speed circuit.

One way of elininating this false synchronization position is to drive the multiple-speed synchro at any odd multiple of the single-speed

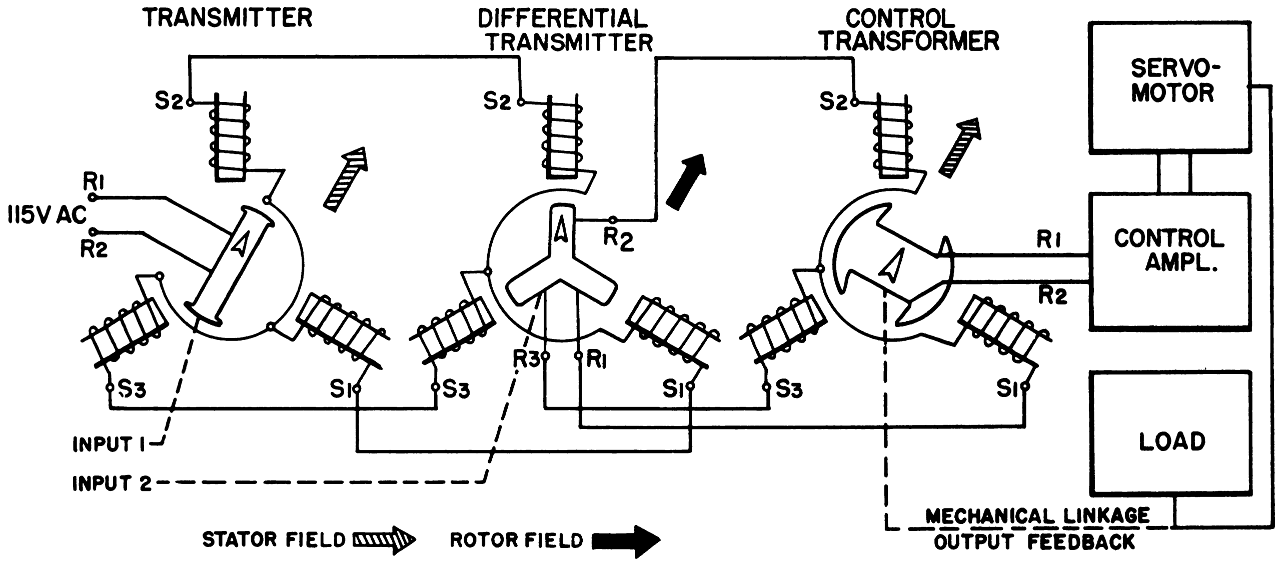

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Figure 12-9.—Synchro differential transmitter used for additional input.

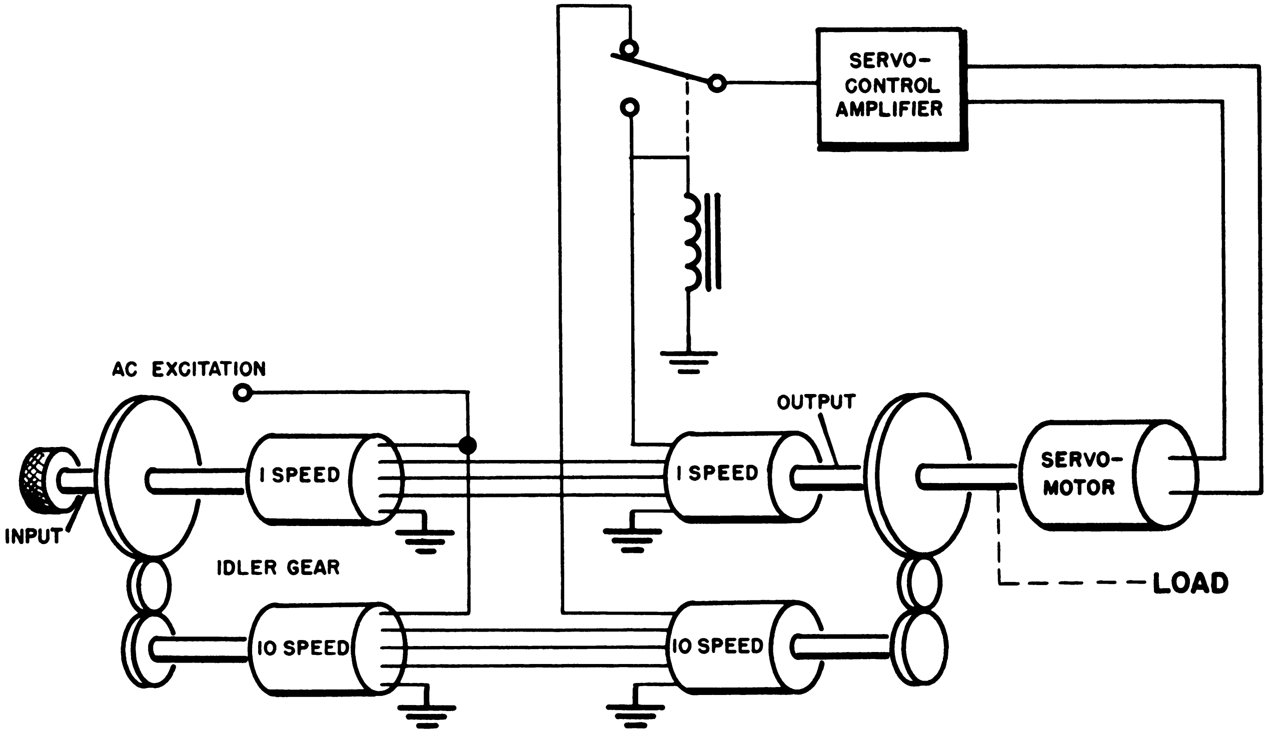

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Figure 12-10.—Multiple-speed data transmission system.

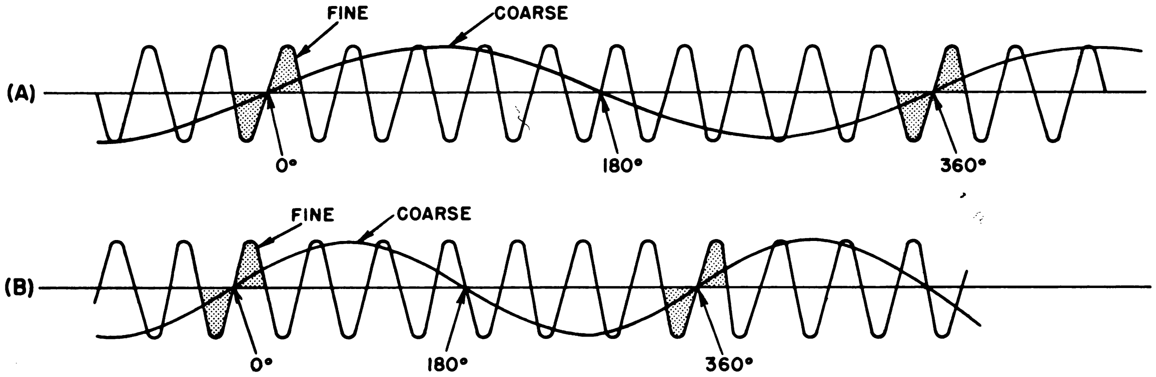

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Figure 12-11.—Phase relationships of fine and coarse synchro voltages. (A) Single speed and 10 speed; (B) single speed and seven speed.

synchro. Figure 12-11 (B) shows the phase relationship of a single-speed and seven-speed system. Although there is still a null of both synchros at the 180° position of the single-speed synchro, their outputs are in phase. This position is an unstable one and the servo will not remain at this point.

The system illustrated in figure 12-10 is not found in operating equipment due partly to the load the relay places on the single-speed synchro. In actual practice, the relay could be controlled by an electronic circuit operated by the synchro voltages. A method commonly used feeds the outputs of the synchros to an electronic circuit biased so that the fine-synchro voltage is not used when the coarse-synchro voltage is high. This method does not require a relay.

The disadvantage of using multiple-speed error detectors is the need of an additional synchro system and switching circuit if false synchronization is to be avoided. The increased servo accuracy resulting from the amplification of the error signal and the effective reduction of inherent synchro errors account for the wide use of these multiple-speed data transmission systems.

SERVOCONTROL AMPLIFIERS

In figure 12-5, the output of the error detector (error voltage) is fed to the servocontrol amplifier. This signal is small in amplitude and requires sufficient amplification to allow actuation of the prime mover. In addition to amplification, the servocontrol amplifier must, in some cases, transfer the error signal into suitable form for controlling the servomotor or output member. It may also include provisions for special characteristics necessary to obtain stable, fast, and accurate operation.

Servoamplifiers used in aircraft armament control equipment are limited to electronic and magnetic types. The operation and explanation of electronic amplifiers and their circuits are covered in Basic Electronics.

In addition to the requirements of basic amplifiers, servoamplifiers must also meet certain additional requirements as follows:

1. A flat gain versus frequency response for a frequency well beyond the frequency range used.
2. A minimum of phase shift with a change in level of input signal. (Zero phase shift is desired but a small amount can be tolerated if constant.)
3. A low output impedance.
4. A low noise level.

Servoamplifiers may utilize either a-c or d-c amplifiers or in some instances a combination of the two. However, the application of d-c amplifiers is limited by such problems as drift and provisions for special bias voltages needed in cascaded stages. Drift, a variation in output voltage with no change in input voltage, can be caused by a change in supply voltage or a variation in value of a component. Consequently, many servoamplifiers utilize a-c amplifiers for voltage amplification. Amplifiers are discussed further in conjunction with other circuits later in the chapter.

MODULATORS

As pointed out previously, a-c amplifiers are more satisfactory for amplifying the error signal. However, some aviation armament control equipment utilize a d-c voltage for an error signal. The d-c error voltage may be changed to an a-c signal by the use of a modulator (sometimes called a chopper). Modulator circuits used in servocontrol amplifiers must be phase sensitive and produce an a-c output signal that is proportional to the d-c input signal in amplitude and the phase of it indicative of the polarity.

Vibrator Modulators

A modulator may be either an electromechanical vibrator or an electronic circuit. An example of a vibrator is shown in figure 12-12. An a-c supply voltage is employed to vibrate the contacts of the vibrator in synchronism with the supply voltage. The d-c error voltage is applied to the center contact of the vibrator. Assume that the reference voltage will cause the center arm to contact point A during the first half cycle and point B during the second half cycle. The output is represented by waveform B if the error voltage is positive and by waveform C when the error voltage is negative.

Electronic Modulator

An example of an electronic modulator circuit is shown in figure 12-13. The input d-c error voltage is impressed between E1 and ground. The a-c reference voltage along with the action of V1, V2, R2, and R3 effectively clamp the output E2 at zero potential for onehalf cycle of the reference voltage. To accomplish this, the following conditions must exist:

1. R1 must be much larger than R2.
2. R2 and R3 are equal.
3. V1 and V2 must be matched.

With no reference voltage applied, the output E2 is the same as E1, the error voltage. With a reference voltage applied, making the plate of V2 positive and the cathode of V1 negative, current flows through V1, R2, R3, and V2. Since R2 equals R3, the voltage E3 equals E4. This effectively clamps the voltage at the junction of R2 and R3 at ground potential giving a zero output

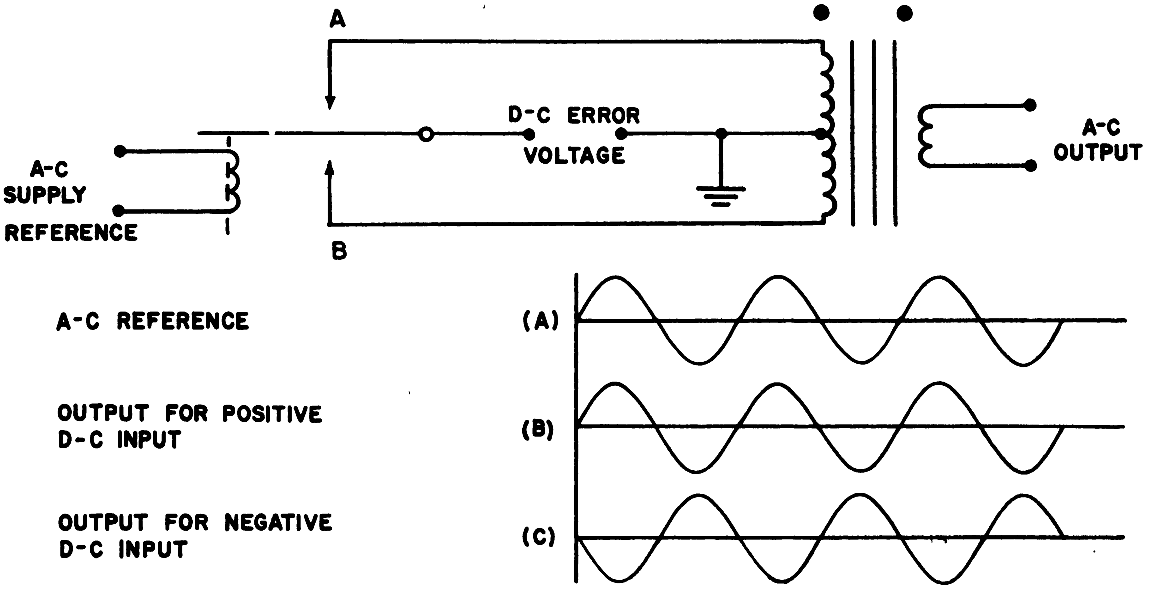

Figure 12-12.—Vibrator modulator.

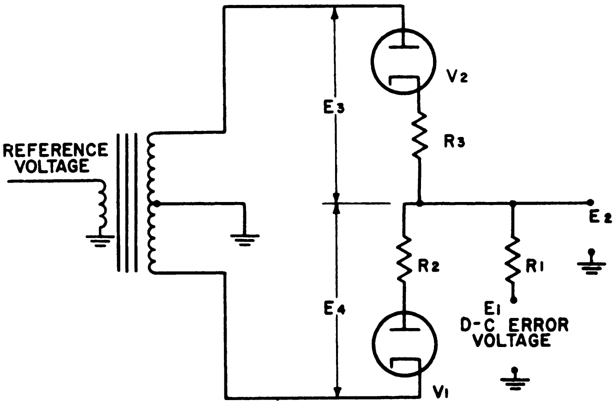

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Figure 12-13.–Electronic modulator.

at E2. On the reverse half cycle V1 and V2 are nonconducting with E2 equaling E1. This results in an a-c output whose amplitude is determined by the amplitude of the d-c error signal and whose phase is determined by the polarity of the error voltage.

The examples shown above are representative of those used in aviation electronic control equipment. Variations of these circuits may be encountered. However, they all perform the same function with only slight differences in their operating principles.

PHASE DETECTORS

In the preceding section of this chapter, it has been stated that the a-c amplifier has inherent advantages over the d-c amplifier, that a d-c error voltage can be changed into an a-c signal, and the a-c signal can be amplified and applied to an a-c servomotor. However, some equipment utilize d-c servomotors which necessitates converting the a-c signal to d.c. To accomplish this, a phase detector, sometimes referred to as a demodulator, is used.

Diode Phase Detectors

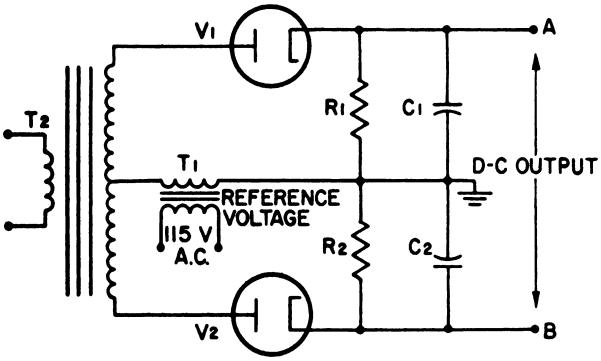

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Figure 12-14.–Diode phase detector.

A typical diode phase detector is shown in figure 12-14. As illustrated, an a-c excitation voltage serves as the reference voltage to the detector. This voltage must come from the same source that is supplying a-c excitation to the synchro system, or whatever type of error detector that is being employed, and must be in phase with the excitation voltage. This permits a phase comparison of the error voltage with the reference voltage. The plates of the two diodes are supplied with this reference voltage in such a manner that the two plate voltages are in phase. Assuming that there is no error signal from T2 to the plates of the diodes at the time the plate voltages are on a positive half cycle, the two diodes conduct equally. The voltages produced across R1 and R2 are equal, making the cathode of V1 and V2 at equal potential with respect to ground. With the two output terminals at the same potential, the output voltage remains at zero as long as there is no error signal applied.

If an error signal is applied to T2 making the plate of V1 positive at the same instant the reference voltage on the plates of V1 and V2 is on its positive half cycle, V1's conduction is increased over the no-signal condition while the voltage at the plate of V2 is decreased with a consequent reduction in conduction of V2. Since the voltages applied to the plates are both alternating, the voltage developed across R1 and R2 would also be alternating. However, R1C1 and R2C2 form a long time constant to the input frequency and filter most of the ripple, giving a d-c output.

If the error signal applied to T2 is changed by 180°, V2 would now increase its conduction while the conduction of V1 would be reduced. This would result in an output voltage of reversed polarity. Variations of the diode phase detector may be encountered; however, their principle of operation is essentially unchanged.

Triode Phase Detectors

A phase detector using triode tubes (fig. 12-15) also provides amplification of the error signal in addition to phase detection. In this circuit, as in the previous one, the plates of the tubes are supplied with the a-c reference voltage in such a manner that the plate voltages are in phase. For the purpose of explanation, assume that no error signal is present at T2. When the plates of V1 and V2 are positive, the two tubes conduct equally. The plate current that flows sets up magnetic fields in the d-c motor exciter windings that are equal and opposite; therefore, the fields cancel and produce no output. When the plate voltages are on a negative half cycle, C1 and C2 discharge through their respective exciter windings to maintain a constant direct current through the windings.

If an error signal is introduced into the primary of T2 with a phase relationship that causes the grid of V1 to be positive at the same instant that the plate of V1 is positive, the following conditions exist:

1. On this half cycle the conduction of V1 is increased above its no error signal condition.
2. The heavier plate current causes a stronger field to be created in the upper exciter winding.
3. At this same instant, since the grid of V2 is on a negative half cycle, its average conduction is reduced to a level below that of its no error signal condition.
4. The lower level of plate current causes a weaker field to be produced in the lower exciter winding.

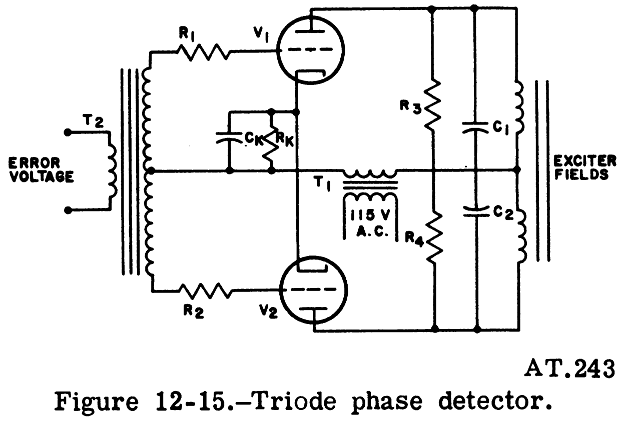

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Figure 12-15.—Triode phase detector.

5. Since the magentic fields produced in the exciter windings are no longer of equal amplitude, they no longer cancel each other.
6. The exciter produces an output voltage of a polarity controlled by the polarity of the resultant field and of an amplitude controlled by the relative strength of this resultant field.
7. The exciter output causes the proper mechanical actions necessary to reduce the amplitude of the error to zero.
8. As the error signal is reduced to zero, the current conduction through V1 and V2 is again balanced. Also the exciter fields are equal and opposite, canceling each other, reducing the exciter output to zero, and stopping the mechanical action. Resistors R1 and R2 prevent excessive grid current when the error angle is large.

SPECIAL CIRCUITS

It has been shown how a servocontrol amplifier may have provisions for changing a d-c error signal to an a-c signal and how an a-c error signal may be detected to supply a d-c voltage to a servomotor or controller. In the following paragraphs other special amplifier circuits are discussed.

Two-Stage D-C Servocontrol Amplifier

If somewhat more power is required by the servomotor than can be supplied by the servoamplifier (fig. 12-15), a push-pull d-c amplifier can be inserted between the phase-sensitive triodes and the servomotor. In the schematic diagram (fig. 12-16), the output of the phase detector triodes is now taken across the parallel RC networks in the plate circuit.

The bias source, E_{CC}, for the d-c amplifier is connected with its positive terminal on the grid side. This positive voltage subtracts from the highly negative voltage across the capacitor to give a resulting negative voltage which allows the tube to operate on the linear portion of its characteristic curve.

When there is no signal input from the error detector, the plate currents of the phasesensitive rectifiers are equal. The outputs of V1 and V2 are applied to the grids of V3 and V4, respectively. Equal output from V1 and V2 causes equal currents to flow in V3 and V4. With R5 and R6 equal in resistance and current, the volt-

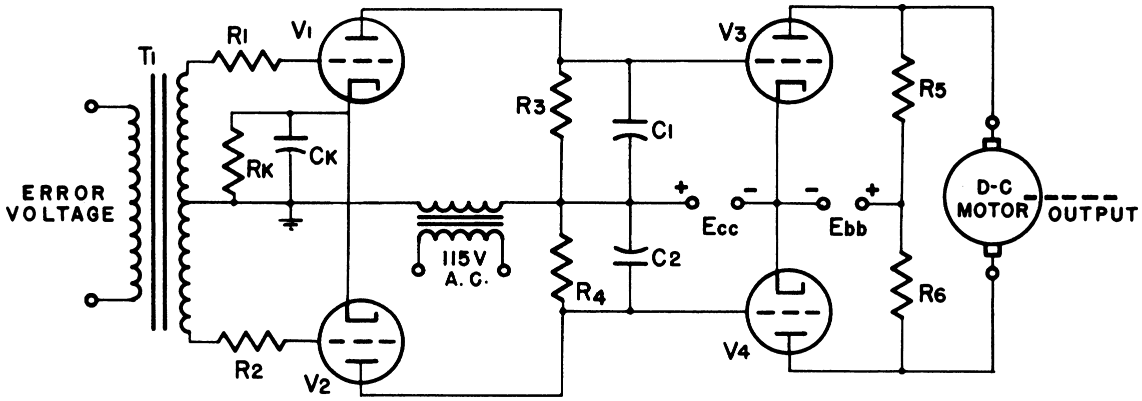

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Figure 12-16.–Two-stage d-c servocontrol amplifier.

age across the motor is zero. Consequently, the motor does not turn.

When there is a signal output from the error detector, the following action occurs. Assume that the error signal makes the grid of V1 positive and the grid of V2 negative. The plate current of V1 increases and the plate current of V2 decreases. An increasing plate current in V1 increases the charge on capacitor C1 and conversely a decreasing plate current in V2 decreases the charge on capacitor C2. As a result of this change in error signal, the voltage on the grid of V3 is now more negative than the voltage on the grid of V4. This increased negative voltage on the grid of V3 decreases its plate current and the voltage e3 decreases. The decreased negative voltage on the grid of V4 increases its plate current and the voltage e4 increases. As a result, a voltage difference appears across the motor armature and the motor rotates.

When the output signal from the error detector reverses in phase, the sequence of events that follow will cause the motor to reverse its direction of rotation.

Magnetic Amplifiers as Servocontrol Amplifiers

The servomotor used in conjunction with the magnetic amplifier shown in figure 12-17 is an a-c type. The uncontrolled phase may be connected in parallel with transformer T1 by utilizing a phase shifting capacitor, or it may be connected to a different phase of a multiphase system. The controlled phase is energized by the magnetic amplifier and its phase relationship is determined by the polarity of the d-c error voltage.

The magnetic amplifier consists of a transformer (T1) and two saturable reactors, each having three windings. Note that the d-c bias current flows through a winding of each reactor and the windings are connected in series-aiding. This bias current is supplied by a d-c bias power source. A d-c error current also flows through a winding in each reactor; however, these windings are connected in series-opposing.

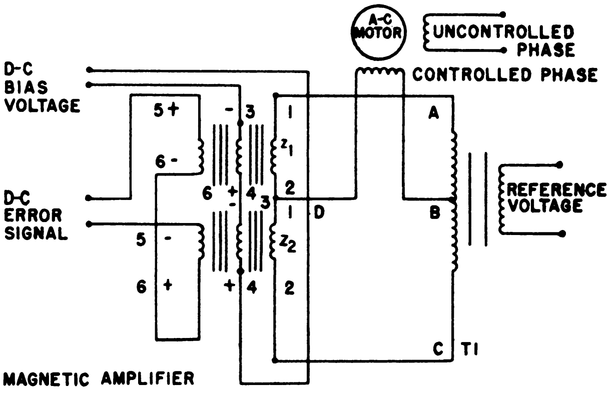

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Figure 12-17.–Magnetic amplifier servocontrol amplifier.

The reactors Z1 and Z2 are equally and partially saturated by the d-c bias current when no d-c error signal is applied. The reactance of Z1 and Z2 are now equal, resulting in points B and D being at equal potential. There is no current flow through the controlled phase winding.

If an error signal is applied causing the current to further saturate Z2, the reactance of its a-c winding is decreased. This current through Z1 tends to cancel the effect of the d-c bias current and increase the reactance of its a-c winding. Within the operating limits of the circuit, the change in reactance is proportional to the amplitude of the error signal. Hence, point D is now effectively connected to point C causing motor rotation. Reversing the polarity of the error signal causes the direction of rotation to reverse since point D is effectively connected to point A.

The basic magnetic servoamplifier discussed above has a response of approximately 6 to 20 hertz. In some applications this delay would be excessive, creating too much error. However, this delay can be reduced to about one hertz by using special push-pull circuits.

Amplifier Integrator

A simple and commonly used integrator consists of two circuit elements: a resistor and capacitor. (See fig. 12-18.) The voltage across the capacitor is proportional to the integral of the charging current. It can be explained by considering that the voltage across a capacitor is

$$E = \frac{Q}{C}$$

For any given capacitor (C), the voltage depends directly on the charge (Q) which is the imbalance of electrons on the two capacitor plates. The amount of this charge depends on the current flow and the time which this flow exists.

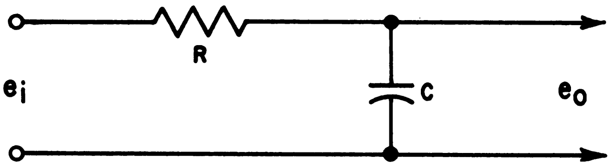

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Figure 12-18.—Simple integrator.

The fact that the voltage is proportional to the integral of the charging current allows the RC circuit to be used as an integrator. The capacitor voltage is the integrator output. Provision must be made to supply a charging current that is proportional to the input information. The purpose of the resistor is to produce this proportional current from an input signal voltage "e_i." At the instant this voltage is applied, the charging current becomes

$$i = \frac{e_i}{R}$$

Unfortunately this proportionality does not continue to exist. As the capacitor becomes charged, the capacitor voltage opposes the charging current, and the charging current becomes less proportional to the input signal. This results in an error in the output. The ideal output, for a constant input signal is a steadily increasing output. This steady increase is attained only when the signal voltage is first applied and the capacitor has not become appreciably charged.

A remedy to this error in the RC integrator is to use a circuit with a long time constant. Such a circuit delays the charging of the capacitor. The result is a more accurate integration of an input signal. The ideal output would be a perfect triangular wave. Although a long time constant produces more accurate results, it also provides a much lower output for the same input signal. Better integration is possible by the use of a high gain, feedback amplifier.

An amplifier integrator is illustrated in figure 12-19. This circuit arrangement uses a high gain amplifier and is known as the Miller integrator. The amplifier produces an output which is not limited by the input signal as it is in the simple RC integrator. The amplifier also supplies any energy which is required in the output. The function of the input signal is to control the charging current.

The operation can be explained by assuming a constant input as shown in figure 12-19 (A). At the start, assume the initial condition is zero, that is,

$$e_i = e_g = e_o = 0$$

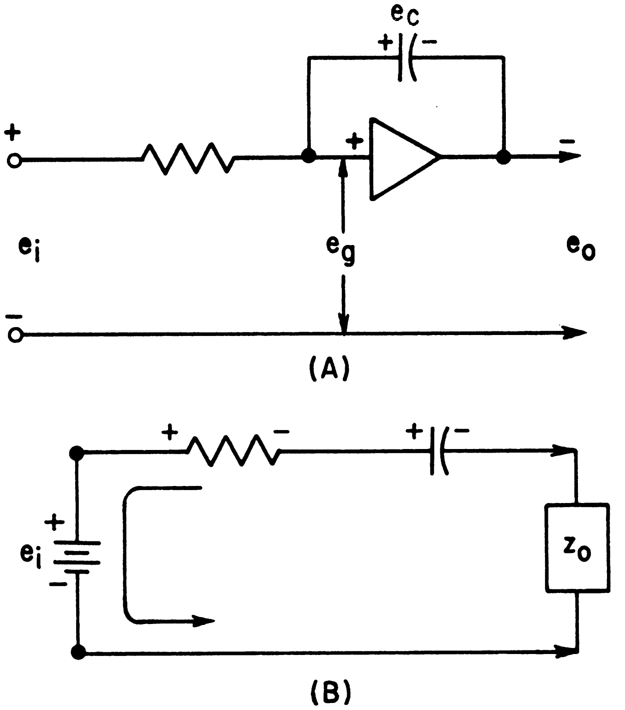

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Figure 12-19.–Amplifier integrator.

Also assume that the capacitor is discharged. The positive voltage to be integrated, “e_i,” is then applied. The capacitor charges with a polarity as shown, since electrons are attracted from the left plate. The charging path is shown in figure 12-19 (B).

A voltage measured at the amplifier input, “e_g,” tends to rise in the positive direction since this point is directly coupled to “e_i,” However, this rise tends to be opposed by the degenerative feedback voltage from the output. The output will be $-Ae_g$ (e_o). The letter “A” stands for the amplifier gain. The minus sign indicates that the out polarity or phase is opposite to the input. The output changes “A” times faster or steeper than “e_g.” The output voltage is negative and aids the charging of the capacitor.

For a certain input voltage, the charging current is limited to a particular value which tends to keep “e_g” practically zero. If the current should exceed this value, “e_g” would decrease a small amount due to the increased voltage drop across R. Then e_o would decrease, and the charging current would decrease to the original value. If the initial charging current should decrease, the opposite action would occur. The value of the charging current is therefore stabilized to a specific value proportional to the input voltage. This eliminates the error caused by “e_i” and the charging current not remaining proportional in the fundamental RC integrator.

This constant charging current must be produced by “e_o” despite the fact that the steadily increasing capacitor voltage opposes the charging current. To do this, “e_o” must also steadily increase. This steady increase in “e_o” is exactly the integrator output voltage desired for a constant signal input.

Similar action would be produced for a condition in which the input signal suddenly became negative. Polarities then would be in reverse to those shown in the example given. Remember that simple examples are used for explanation on the assumption that the desired result also will be produced for a more complicated signal input. Removal of “e_i” would produce little effect upon the the output which existed at that instant, since the amplifier output would oppose the tendency for the capacitor to discharge.

The limits for “e_o” are determined by the amplifier and not by “e_i” or the range of “e_g.” The output range would be designed to produce an increasing output for any probable input amplitude and period of application. The exception to this would be an integrator which was designed to function also as a limiter.

OUTPUT DEVICES

The output of the servocontrol amplifier is fed to an output device. The functions of this device, usually a servomotor, are to supply torque, power, and dynamic characteristics required to position the servo load. Ideally, the power device should require small power from the control amplifier, accelerate rapidly, be of small size and weight, be of lasting endurance, have small time lags, and have an adequate speed range. In aviation electronic systems, the electric motor is most frequently used as an output device.

ELECTRIC MOTORS

In aviation electronic equipment, electric motors are primarily used to drive the servo load. The type of electric motor used within a particular equipment is determined by such factors as type of power available, output power, speed range, inertia, and electrical noise.

Alternating-Current Motors

Alternating-current motors are frequently used in low power servo applications because of their simplicity, reliability, absence of commutator sparking, and rapid response. However, they have a disadvantage of having a narrow speed range characteristic. The theory of operation of a-c motors is discussed in Basic Electricity. However, this training manual briefly discusses the types of motors applicable to servosystems.

The 2-phase induction motor is the most widely used a-c servomotor. The stator of the motor consists of two similar windings which are positioned at right angles to each other. The rotor may be wound with short-circuited turns of wire or it may be a squirrel cage rotor. The squirrel cage rotor is the type most frequently encountered. It is made up of heavy conducting bars which are set into armature slots, the bars being shorted by conducting rings at the ends.

Two a-c voltages 90° out of phase must be applied to the stator windings in order for the motor to turn. These out-of-phase voltages generate a rotating magnetic field which induces a voltage in the rotor. This induced voltage generates a magnetic field in the rotor that is displaced 90° from the stator magnetic field. The interaction of the two magnetic fields causes the armature to rotate.

As stated previously, the voltage to the two stator windings must be 90° out of phase to cause the rotor to turn. The direction of rotation is determined by the phase relationship of the stator windings which, in turn, is determined by the servo error detector. One phase is connected directly to one of the stator windings while the other phase is used to energize an error detector. The resulting error voltage is either in phase or 180° out of phase with the signal applied to the error detector. This will cause the controlled phase to either lead or lag the uncontrolled phase by 90°.

Most induction motors have low starting torque and high torque at high speed. For servo applications, it is desirable to have high starting torque in order that the system may have a low time lag. This may be accomplished by increasing the armature resistance with the use of materials such as zinc for the conducting bars. This increased torque at low speed results in decreased torque at high speed. However, increased stability of the servosystem is a desirable result of this change.

Split-phase a-c motors are similar to the 2-phase induction motor.It differs only in that a phase shifting network is used to shift the phase of the voltage supplied to one of the windings by 90°. This is usually accomplished by connecting a capacitor in series with the uncontrolled winding of the stator. Direction of rotation and reversal is accomplished in the same manner as in the 2-phase motor discussed above.

Other types of motors that may be used with an a-c power supply are shaded pole, universal, and repulsion motors. They utilize various methods of obtaining rotation reversal.

Direct-Current Motors

Direct-current motors have an advantage of having higher starting torque, reversing torque, and less weight for equal power than a-c motors.

Series motors are characterized by their high starting torque and poor speed regulation with a change in torque. Higher torque can be obtained on reversal of direction with a series motor than any other type. However, it is a unidirectional motor and requires special switching circuits to obtain bidirectional characteristics. This is normally done by switching either the armature or field connections but not both.

A variation of the series motor that has bidirectional characteristics is the split-series motor. The motor has two field windings on its frame, only one of which is used for each direction of rotation. This reduces the number of relay contacts required for reversing by one-half. This double winding also reduces the torque capabilities of the motor as compared to a straight-series motor wound on the same frame.

The most frequently used d-c servomotor is the shunt motor. Its direction of motion is controlled by varying the direction of flow of either the armature or field current. The uncontrolled current is usually maintained constant to preserve a linear relationship between the motor output torque and the voltage or current input. The field windings are usually two differentially wound coils to facilitate direction control of the field current by the servocontrol amplifier. The field current is usually controlled with receiving type vacuum tubes. The larger armature currents require thyratrons or generators as current regulators.

MAGNETIC CLUTCHES

Any device utilizing an electrical signal that may be used to control the coupling of torque from an input shaft to an output shaft is a magnetic clutch. This coupling may be accomplished by the contact between friction surfaces or by the action of one or more magnetic fields. A magnetic clutch is used only to couple the input torque to the output shaft. Thus, it is capable of controlling large amounts of power and torque for its size and weight. The magnetic clutch may be used with a large flywheel driven at high speed by a small motor. This allows the flywheel to impart very large acceleration to the load when the magnetic clutch is energized.

There are two distinct types of magnetic clutches. Some transmit torque by physical contact of frictional surfaces. Others utilize the action of magnetic flux produced by two sets of coils or one set of coils and induced eddy currents resulting from rotating the one set of coils near a conducting surface. The eddy current type of clutch offers smoother operation and has no problem of wear due to friction. Both types have suitable control characteristics and are found in servomechanisms.

HYDRAULIC DEVICES

Hydraulic components used in servomechanisms are frequently found in aviation electronic equipments such as radar antennas. Hydraulic power devices, such as motors and associated control valves, have an advantage of a response much faster than the best electric motors and equal to that of a magnetic clutch system. They also require a minimum of maintenance, have very high accuracy, and are well adapted to heavy loads.

The essential components of a hydraulic system are:

1. Source of high pressure oil and sump to receive discharged oil.
2. Control valve and means of employing an actuating signal.
3. Actuator (motor or cylinder).

The theory of operation of a hydraulic system is discussed in Fluid Power, NavPers 16193-A.

The source of high pressure oil serves as a source of power to operate the actuator. However, this source of power is controlled by the control valve. This valve is actuated by the output from the servocontrol amplifier. This control is normally accomplished by feeding the error signal to a solenoid controlled valve. However, the error signal could be used to drive an electric motor which, in turn, actuates the control valve. The actuator is usually in the form of an axial motor which must be a reversible and variable speed type. Some applications may employ a cylinder where linear motion is required for positioning.

SERVOMECHANISM OSCILLATION

Servomechanisms are utilized for various functions and must meet certain performance requirements. These requirements not only concern such things as speed of response and accuracy, but the manner in which the system responds in carrying out its command function. All systems contain certain errors, the problem being to keep them within the allowable limits.

As discussed previously, the servomotor must be capable of developing sufficient torque and power to position the load in a minimum of time. The servomotor and its connected load have sufficient inertia to drive the load past the point of command position. This overshooting results in an opposite error voltage, reversing the direction of rotation of the servomotor and the load. The servomotor again attempts to correct the error and again overshoots the point of correspondence with each reversal requiring less correction until the system is in correspondence. The time required for the oscillations to die out determines the transient response of the system and can be greatly reduced by the use of damping.

DAMPING

The function of damping is to reduce the amplitude and duration of the oscillations that may exist in the system. The simplest form of damping is viscous damping. Viscous damping is the application of friction to the output load or shaft that is proportional to the output velocity. The amount of friction applied to the system is critical and will materially affect the results of the system. When just enough friction to prevent overshoot is applied, the system is said to be critically damped. When the friction is greater than that for critical damping, the system is overdamped. However, when damping is slightly less than critical, the system is said to be slightly underdamped, which is usually the desired condition. The application of friction absorbs power from the motor and is dissipated in the form of heat.

A pure viscous damper would absorb an excessive amount of power from the system. However, a system having some of the characteristics of a viscous damper with somewhat less power loss is used in actual practice. The first of this type of damper to be discussed utilizes a dry friction clutch to couple a weighted flywheel to the output drive shaft. A flywheel has the property of inertia which may be defined as that property of matter by which it will remain at rest or in uniform motion in the same straight line or direction unless acted upon by some external force.

However, since the flywheel is coupled to the output shaft with a friction clutch, any rapid change in velocity of the output member causes the clutch to slip. This slipping effectively disconnects the flywheel instantaneously but allows sufficient power to be coupled to the flywheel to overcome its inertia. As the inertia is gradually overcome, the flywheel gains speed and approaches the velocity of the output member. As the point of correspondence is neared and the error signal is reduced, the inertia of the flywheel gives up power to the system, causing the load to increase its overshoot. When the system attempts to correct for this overshoot, the inertia of the flywheel adds to the output load, reducing the effect of the correcting signal. This effect dampens the oscillations in the system, reducing its transit time.

Another type of damper used is the eddy current damper. This damper utilizes the interaction of induced eddy currents and a permanent magnet field to couple the output shaft to a weighted flywheel.

The effect of damping is shown in figure 12-20. The soild line shows the action of the load without damping. The time required to reach a steady-state condition without damping should be noted. This time is greatly reduced although the initial overshoot is increased.

As shown in figure 12-20, viscous dampers effectively reduced transient oscillations, but it also produced an undesired steady-state error (velocity lag or position error). Since the friction damper absorbs power from the system, its use is normally limited to small servomechanisms.

To overcome the disadvantages of the viscous dampers and still provide damping, error-rate damping is used. This type of damping consists of introducing a voltage that is proportional to the rate of change of the error signal. This voltage is fed to the servocontrol amplifier and combined with the error signal. Figure 12-21 shows the effect of error-rate damping on the torque output of the servomotor. Curve A shows the torque resulting from the error voltage; curve B shows the torque resulting from the error-rate damper; and curve C depicts the resultant of curves A and B. It should be noted that torque resulting from the damper increases the total torque as long as the error component is increasing. Once the error component starts to decrease, the error-rate damper produces a torque in an opposite direction reducing the transit time of the system.

There are two methods of generating an error-rate voltage normally found in aviation

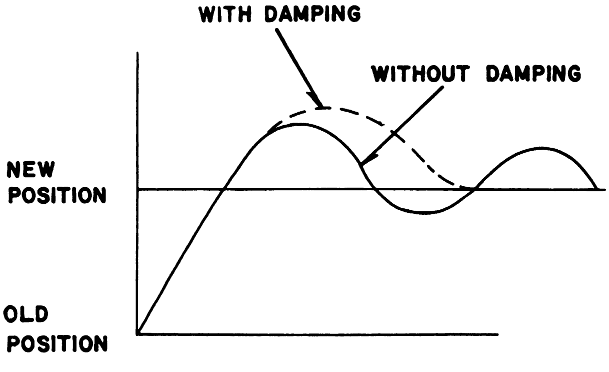

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Figure 12-20.—Effect of friction damper.

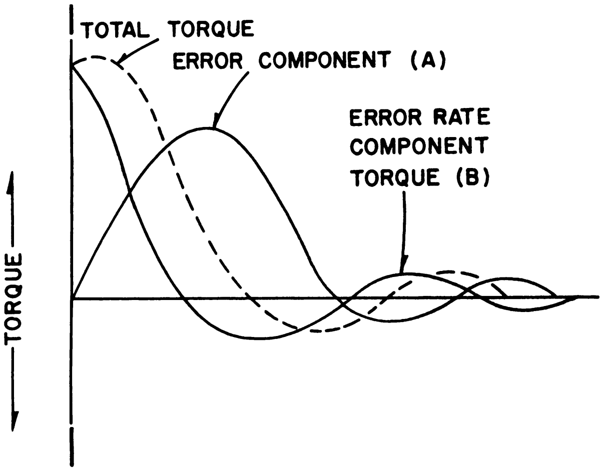

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Figure 12-21.–Torque variations using error-rate damping.

electronic equipments. They are the tachometer and electrical networks. The tachometer error-rate damper utilizes a device which is essentially a generator having an output voltage proportional to its shaft speed. The tachometer is connected to the shaft of the output member giving a voltage proportional to its speed. The output voltage is fed to a network that modifies this voltage so that it is proportional to a change in input voltage. This voltage is fed back to the servocontrol amplifier and added with the error signal as shown in figure 12-21.

Electrical networks used for error-rate damping consist of a combination of resistors and capacitors used to form an RC differentiating network. For a detailed explanation of RC circuits, refer to Basic Electricity. These networks, sometimes referred to as phase advance or lead networks, vary in design, depending on the type of error signal. However, in practice, networks are normally limited to the d-c type. (See fig. 12-22.) This is because of the unstable results that would be caused by a small change in frequency of the power source. An a-c system may utilize a d-c network by first using a demodulator (detector) prior to the network. However, the output of the network must be modulated for use in the remainder of the a-c system. Like the tachometer, the output of the network is fed to the servocontrol amplifier.

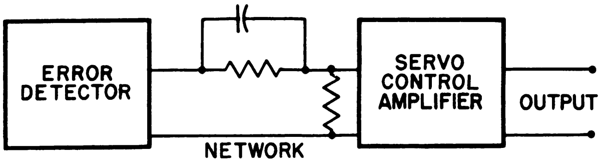

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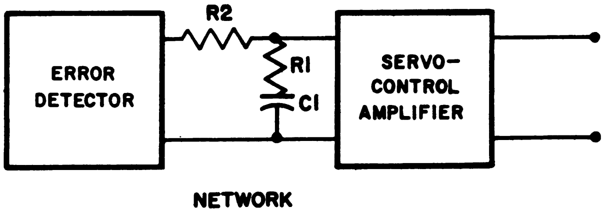
Figure 12-22.–Error-rate stabilization network.

INTEGRAL CONTROL

Servomechanisms used in electronic equipment are sometimes required to follow an input function, the magnitude of which changes at a constant rate with time. Thus, if the input is the angle of a shaft, the velocity of the shaft may be constant for a substantial percentage of time. The servomechanism may be required to respond to this type of input with substantially zero error. The error that characterizes the servo response to a constant velocity input is known as the velocity error.

To correct for velocity error or an inaccuracy due to a steady-state error, an integral control may be used. This control modifies the error voltage in such a manner that the signal fed to the servocontrol amplifier is a function of both the amplitude and time duration of the error signal. This is accomplished by the use of a variable voltage divider whose output would increase with time for a constant input. As in all voltage dividers, the output is only a portion of the input which effectively reduces the amplitude of the error signal. To compensate for this loss of amplitude, additional amplification must be used either in the form of a preamplifier or a higher gain servocontrol amplifier. With the overall gain of the system now increased to give a normal output for transient error signals, small velocity or steady-state error signals of long duration will result in somewhat increased output to the servomotor due to the action of the integral control.

The integral control (fig. 12-23) consists of a combination of resistors and capacitors connected to make an integrator circuit for a d-c error signal. The value of the components are such that the capacitor does not have sufficient



AT.251
Figure 12-23.–Integral stabilization network.

time to change with fluctuations in error voltage. Only that portion of the transient error signal developed across R1 is impressed on the amplifier. However, with a velocity error or steady-state error of longer duration, the capacitor (C1) charges, increasing the amplitude of the amplifier input.

Networks shown in figure 12-23 are not limited to d-c systems as a demodulator may be used prior to the integrator and its output modulated for easier amplification.

GAIN, PHASE, AND BALANCE

The overall system gain has a most important effect on the servomechanism response characteristics and is one of the more easily adjustable parameters in electronics servocontrollers. Increasing the system gain reduces the system velocity errors and those steady-state errors resulting from restraining torques on the servo load or misalinement in the system. An increase in system gain also increases the speed of response to transient inputs. However, excessive gain always decreases the rate at which oscillatory transients disappear, and continue increase in the system gain eventually produces instability.

Servosystems using push-pull amplifiers must be balanced to insure equal torque in both directions of the servomotor. This adjustment should be checked periodically as a change in value of a component may cause an unbalanced output. Balancing is accomplished by adjusting the system for zero output with no signal applied.

A phase control is included in some servosystems using a-c motors. The two windings of the a-c servomotor must be energized by a-c signals that are 90° apart. A phasing adjustment is normally included in the system to compensate for any phase shift in the amplifier circuit resulting in unstable operation of the system. This adjustment may be located in the control amplifier, or in the case of a split-phase motor, it may be in the uncontrolled winding.

ZEROING SYNCHRO UNITS

In this chapter the importance of accuracy of servomechanisms has been stressed. In any servomechanism using synchro units, it is also very important that the units be zeroed electrically.

For a synchro transmitter or receiver to be in a position of electrical zero, the rotor must be alined with S2, the voltage between S1 and S3, as shown in figure 12-24 (A), must be zero, and the phase of the voltage at S2 must be the same as the phase of the voltage at R1.

TRANSMITTERS AND RECEIVERS

The most common methods of zeroing synchro transmitters and receivers are the a-c voltmeter method and the electrical lock method. The method used to zero a synchro depends upon how the synchro is used. Where the rotor is free to turn the electrical lock method can be used. This is accomplished by connecting S1 and S3 to R2 using a jumper wire and connecting S2 to R1. (See fig. 12-25.) When power is applied, the rotor will position itself in the zero position. After the synchro is zeroed, the pointer is adjusted to indicate zero.

Possibly the great majority of synchros used in aviation electronic equipment have their rotors gear driven or mechanically coupled to a driving member. In these cases it is necessary to use the a-c voltmeter method, zeroing the synchro by rotating the stator or housing until its electrical zero is reached. Before zeroing the synchro, the mechanical unit that positions the synchro must be set to its indexing or ZERO position. This is done by alining the unit to its index and installing its indexing pins in the holes provided for this purpose. The pins hold the unit to its index and keep it from moving.

The a-c voltmeter method is done by connecting the meter and jumper wires as shown in (A) of figure 12-26. Rotate the energized synchro

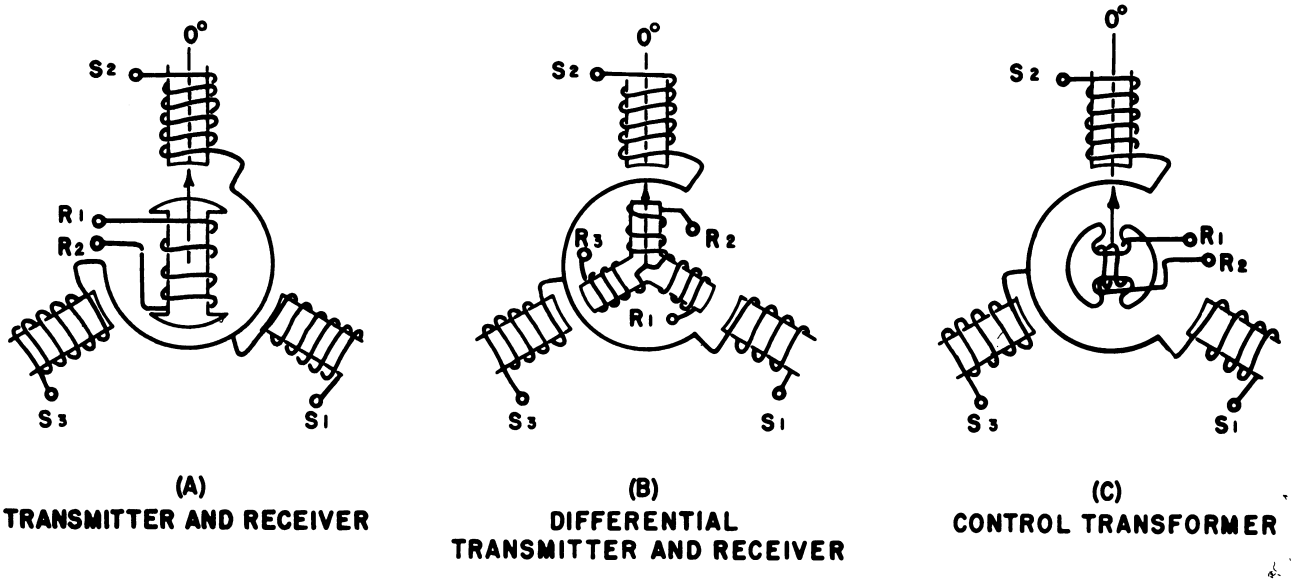


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Figure 12-24.—Synchro electrical zero positions.

until a zero reading is obtained on the voltmeter. Since rotor positions of zero degree and 180° produce this zero reading, it is necessary to determine if the phase of S2 is the same as that of R1. Make the connections as shown in (B) figure 12-26. If the proper polarity relationship exists, the voltmeter indicates less than the excitation voltage being applied to the rotor. If the indication is greater than the rotor excitation voltage, the rotor (or stator) must be rotated 180° and the previous step must be performed again.

The electrical zero position of a synchro differential transmitter or receiver is when the three windings of the rotor are in correspondence with their respective stator windings and their respective voltages are in phase. (See fig. 12-24 (B).)

Because the differential transmitter synchro is normally used to insert a correction into a synchro system, it is usually driven either directly or through a gear train. Before zeroing the differential transmitter synchro, the unit whose position the differential synchro transmits should first be zeroed. After this has been accomplished, connect the differential synchro as shown in figure 12-27 (A). Turn the synchro in its mounting until the voltmeter shows a minimum indication. After completing this step, make the connections shown in figure 12-27 (B). Again turn the synchro slightly in its mounting, until a minimum voltage is indicated by the voltmeter.

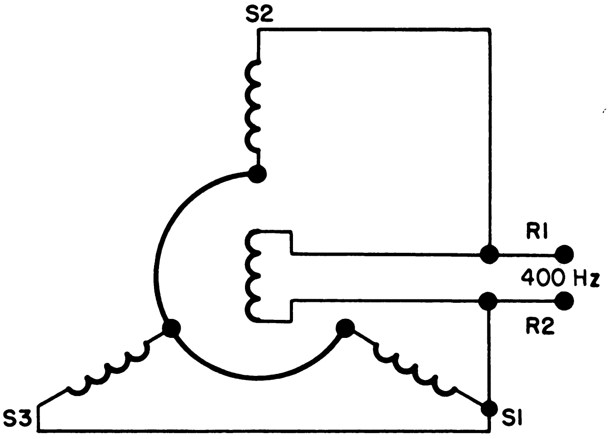

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Figure 12-25.–Electrical lock method of zeroing a synchro.

Electrical zero for a differential receiver is illustrated in figure 12-24 (B). To zero a differential receiver synchro, make the connections shown in figure 12-28. As soon as the power is applied to the synchro, the rotor assumes a position of electrical zero. The dial can be set at zero and the unit reconnected to its circuit.

The synchro control transformer is normally zeroed by using the a-c voltmeter method. It should be remembered that the electrical zero position of the control transformer is 90° from that of a receiver since the rotor winding must be perpendicular to the stator's resulting magnetic field to have a zero output. (See fig. 12-24 (C).) The coarse adjustment is made by connecting the meter and unit as shown in figure 12-29(A). The rotor is rotated to give a minimum or null reading on the voltmeter. The final adjustment is made by connecting the unit as shown in figure 12-29 (B) and displacing the rotor a few degrees in both directions to determine the null or electrical zero position. Once the

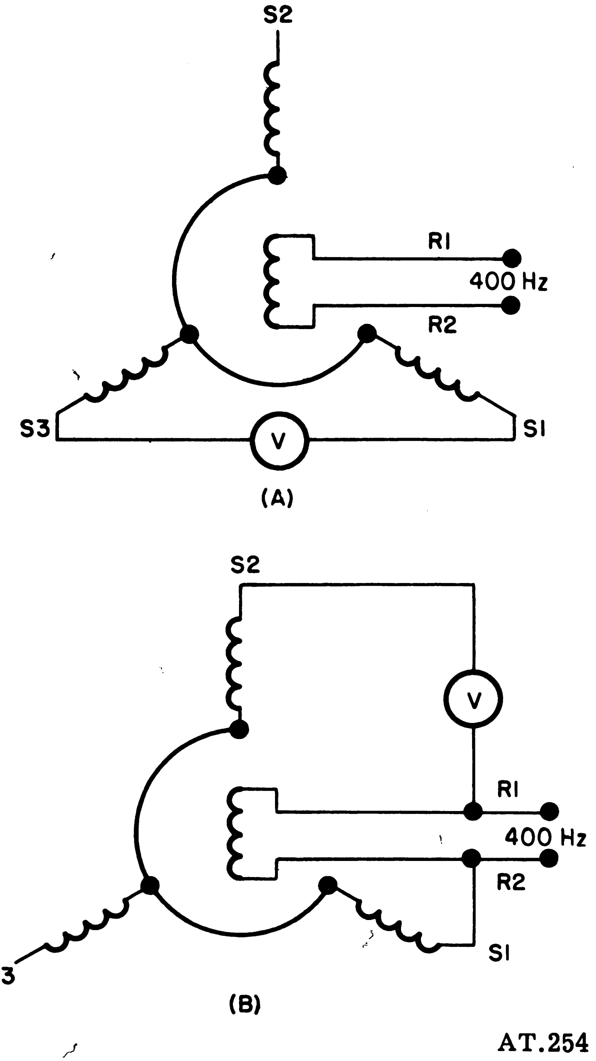

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Figure 12-26.—A-c voltmeter method of electrically zeroing synchro receiver or transmitter.

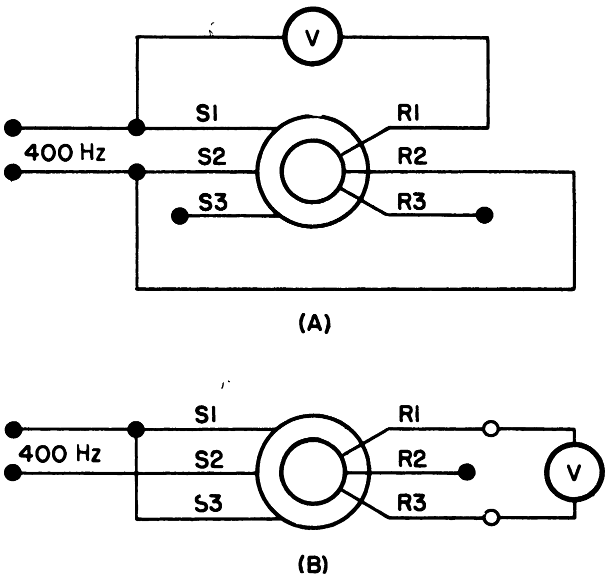

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Figure 12-27.—Electrically zeroing a differential transmitter.

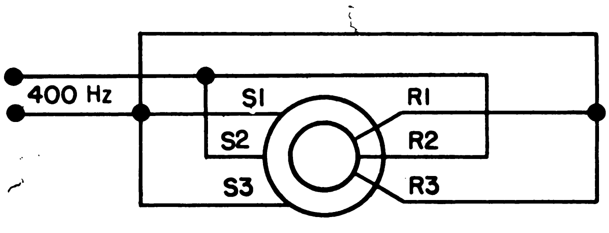

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Figure 12-28.—Electrically zeroing a differential synchro receiver.

zero position has been determined, the unit must be locked as discussed previously.

SYNCHRO ALIGNMENT SET TS-714/U

The Synchro Alignment Set TS-714/U (fig. 12-30) is a portable, general purpose test set used to check the alinement of synchros or resolvers. It can be used to aline any 400-Hz synchro or resolver. In addition to its higher sensitivity, the test set has an additional advantage over the methods previously discussed in that the test set can also supply excitation voltage for the synchro or resolver being alined.

The test set basically consists of a bandpass amplifier and power supply, a synchro or resolver excitation supply with outputs from 3 to 115 volts rms (selected by switch 1 of fig. 12-30) and switching circuits. The output voltages from the synchros or resolvers are applied to the amplifier, the output of which is fed to a phase sensitive detector circuit. The detector's output is metered by the microammeter (2 of fig. 12-30). A meter switch (3) selects the meter sensitivity from 300 volts full scale to 0.1 volt full scale; it also has a calibrate position and an off position.

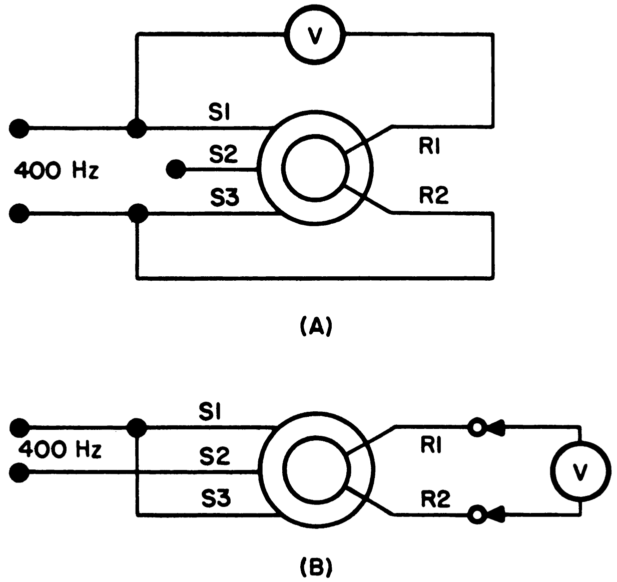

Figure 12-29.–Electrically zeroing a control transformer synchro.

The meter has a zero-center scale and indicates zero when the synchro or resolver is adjusted to either of its two nulls. The synchro or resolver is adjusted to a null position with the function switch (4) in the ZERO position. When the null is reached, the function switch is switched to the POL position and note is taken of the meter reading. Then the function switch is returned to ZERO position and the synchro is rotated 180° to its opposite null. When the opposite null is reached, the function switch is again switched to the POL position and a note made of the reading. The correct null will be the one indicating the lowest reading with the function switch in the POL position. When the synchro is adjusted to this null, it is electrically zeroed with the correct polarity.

For detailed instructions on the use of the TS-714/U, consult Operation and Service Instruction Manual, NA 11-70-FAG-510.

Typical Application

A practical application of a complete servosystem is found in the antenna tilt stabilization circuits of radar systems. Tilt stabilization is used to tilt the angle of the transmitted beam of RF energy to compensate for deviations in the attitude of the aircraft. Throughout the scanning azimuth of the antenna, the beam is maintained at the angle selected by the operator. The selected angle is set by the tilt control on the radar antenna control unit.

The stabilization range on one type of radar is such that if the tilt control is set for 0°, the beam is maintained at this angle for aircraft pitch or roll angles up to -30°. If the tilt control is set for other beam angles, these limits will vary accordingly. A typical tilt stabilization system is illustrated in figure 12-31.

The conditions of flight assumed for reference result in the waveforms shown at the left of the figure. These conditions are as follows:

1. Aircraft is entering a climb.
2. Manual tilt control is set for zero tilt.
3. Tilt stabilizer mechanism is functioning in response to gyro signals.
4. Scanner's instantaneous position is "dead ahead."

NOTE: The amplitude for waveforms 7 and 8 are not drawn to comparative scale.

The tilt stabilization system, shown in figure 12-31 consists of a gyroscope unit, a servoamplifier, the resolver synchro, manual tilt synchro, tilt torque motor, damping signal gengenerator, and followup synchro. The gyroscope unit is separately mounted on the aircraft structure, and the resolver synchro and the servoamplifier are mounted on the antenna frame. The tilt torque motor, damping signal generator, and followup synchros are contained in the tilt servo unit mounted on the rotary section of the antenna. The manual tilt synchro is mounted on the antenna control box.

Stabilization is effected by the use of two signals—the resolver synchro signal, and the manual tilt synchro signal. Separate pitch and roll signals originating in the gyroscope unit are combined in the resolver synchro to produce the single resolver synchro signal. The manual tilt synchro signal originates in the followup synchro and provides the tilt stabilization system with continuous information as to the tilt angle of the reflector. This signal passes through the manual tilt synchro in the antenna control where it is modified according to the setting of the tilt control. The resolver synchro signal and the manual tilt synchro signal differ in phase by 180°. They are combined at the input of the servoamplifier. The amplifier resultant, or error signal, is used to control the tilt torque motor, which corrects the tilt angle of the reflector.

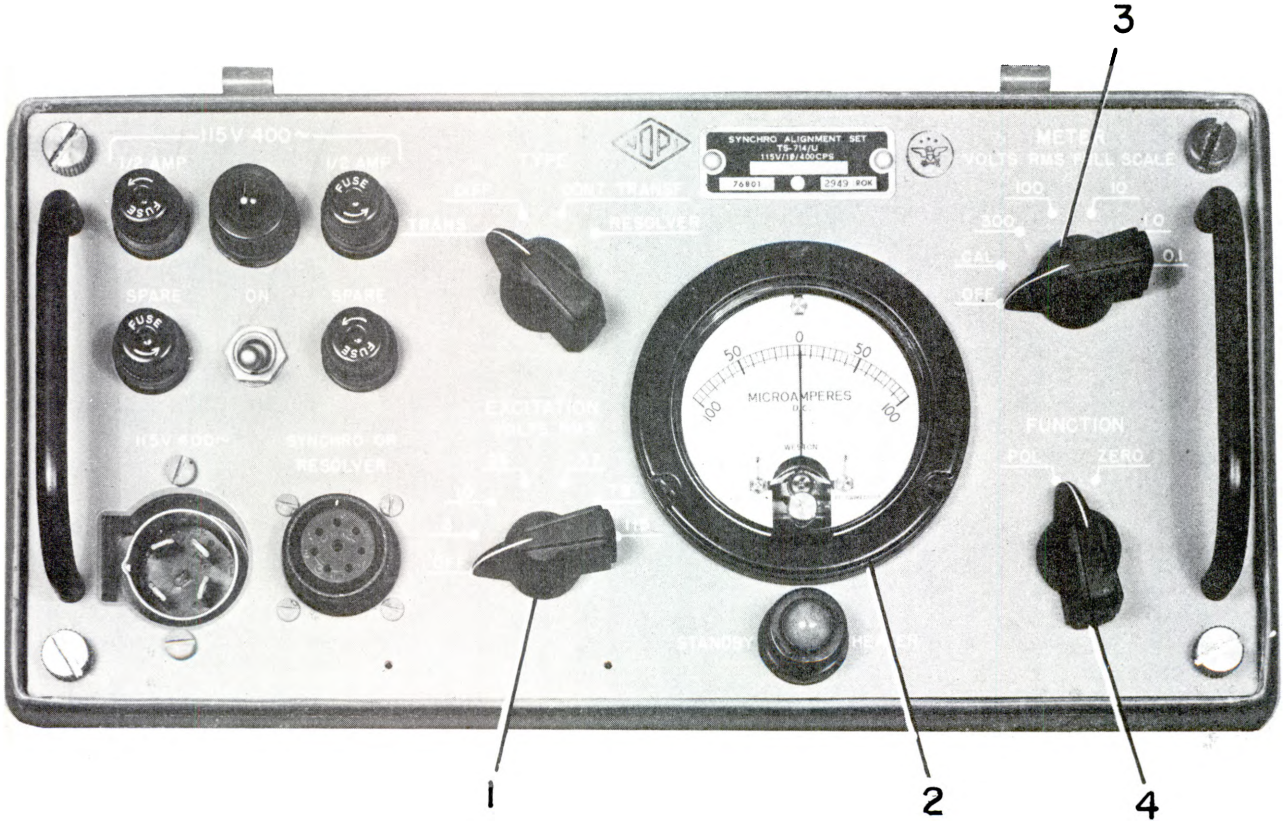

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Figure 12-30.—Synchro Alignment Set TS-714/U, front panel.

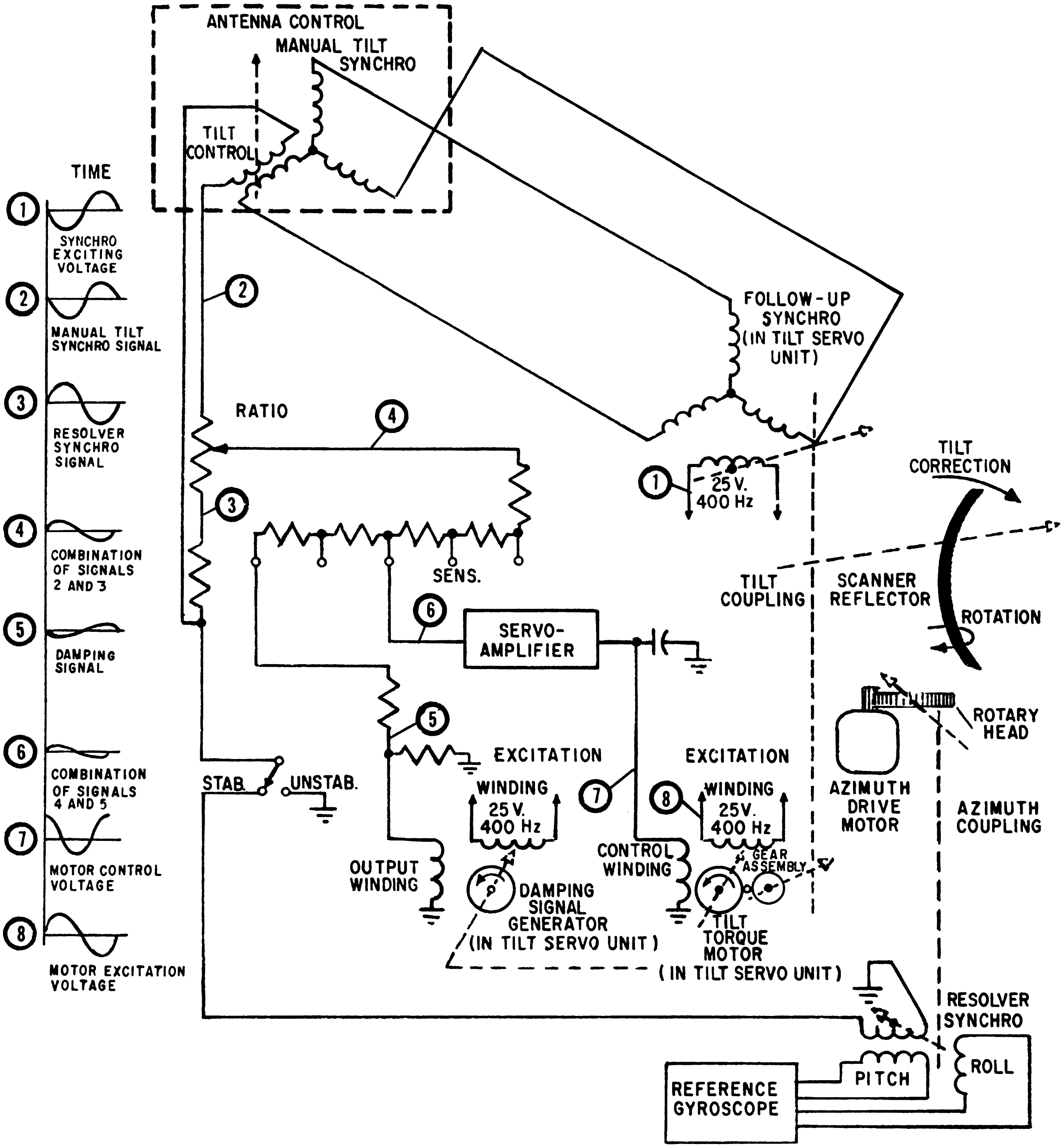

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Figure 12-31.–Radar antenna tilt stabilization servosystem.

CHAPTER 13

ELECTRONIC MAINTENANCE, PART I

The purpose of this chapter is to set forth general maintenance procedures rather than the detailed procedures used with specific units and sets; however, for purposes of illustration, specific electronic units and sets are mentioned. Discussion is given to the troubleshooting procedures used in aircraft as well as on the bench, and repair information concerning electronic circuit construction, replacement of parts, electrical connectors, cables, and terminal blocks.

TROUBLESHOOTING

Much of the technician's time is spent troubleshooting the equipment in the squadron's aircraft. The technician's job is to maintain a great number of units and systems, many of which are quite complex, and which might seem at a glance beyond his ability to maintain. However, the most complex job usually becomes much simpler if it is first broken into successive steps. Any maintenance job should be performed in the following order:

1. Analyze the symptom.
2. Detect and isolate the trouble.
3. Correct the trouble and test the work.

AIRCRAFT PROCEDURES

In troubleshooting, as in most other things, there is no substitute for commonsense. A mistake made by most beginners is to remove major units from the aircraft unnecessarily. When a "squawk" is received, the first step is to determine if the equipment in question is actually faulty. Very often a preliminary check of the system in the aircraft will disclose a faulty control box, frayed or broken wiring, corroded or wet connectors, and, in rare cases, improper operating procedure—especially with new equipment. (Improper operating procedures are especially common when the reported discrepancy involves new equipment or personnel undergoing indoctrination.)

If there is no power present at the input to the equipment, it may be assumed (temporarily) that the set is not defective. Check all applicable switch positions, circuit breakers, fuses, etc., then check for power at the bus which feeds the equipment. Check the tightness and the physical condition of interconnecting cables. Using the wiring diagrams in the applicable manuals, check at successive tie points and splices for continuity, short circuits, or grounds. The procedures to be followed with these tests are discussed later in this chapter under the heading Basic Tests.

If a circuit breaker is tripped or if a fuse is blown, a circuit malfunction is indicated. Power to the circuit containing the "open" should be turned off, and should not be reapplied until the malfunction is located and corrected. The most common causes of tripped or blown circuit protectors are short circuits, faulty grounds, or overload conditions. However, circuit protectors sometimes fail due simply to age or to transient conditions. If, after a thorough check, no apparent reason for the failure can be found, the breaker may be reset or the fuse replaced with the proper size and type, and the power reapplied. If the protector fails again, a malfunction is definitely indicated.

If the analysis does not indicate the existence of a short circuit, faulty ground, or overload condition, but the equipment still does not operate, continue to take measurements with power applied. These measurements should be taken systematically at progressive checkpoints. Particular faults which may interrupt current through a circuit include broken wiring, loose or faulty terminal or plug connections, faulty relays or switches, and uncoupled splices. Be alert for these conditions.

If the defective unit cannot be identified while still installed in the aircraft, it may be advisable to turn off the power and substitute units, one at a time with units which are known to operate properly. As each unit is replaced, power should be reapplied and the system checked for operation or for symptoms of nonoperation. If the system operated normally, the faulty unit has been identified, and the faulty unit may be taken to the shop for corrective maintenance. At this stage of the overall maintenance process, it is also advisable to try to determine the reason for the failure of the unit–it is conceivable that the new unit may also be damaged if the basic cause is not corrected.

Following removal of the defective unit and the subsequent analysis, all other items of the original installation should be reinstalled and safety wired, and an operational check performed. During the operational check, any readjustments or calibrations should be accomplished as required. This should be done prior to clearing the discrepancy on the Maintenance Action Form.

Basic Tests

Several rules are set forth below and are intended as a guide to follow when making the tests described in this section.

1. Always connect an ammeter in series.
2. Always connect a voltmeter in parallel.
3. Never connect an ohmmeter to an energized circuit.
4. Select the highest range first then switch to lower ranges as needed.
5. When using an ohmmeter, select a scale that will result in a midscale reading.
6. Do not leave the selector switch of a multimeter in the resistance position when the meter is not in use because the leads may short together and discharge the internal battery. There is less chance of damaging the meter if it is left on a high a-c volts setting or in the off position if it has one. Meters that have an off position dampen the swing of the needle by connecting the meter movement as a generator. This prevents the needle from swinging wildly when the meter is moved.
7. View the meter from directly in front to eliminate parallax.
8. Observe polarity when measuring d-c voltage or direct current.
9. Do not place meters in the presence of strong magnetic fields.
10. Never attempt to measure the resistance of a meter or a circuit with a meter in it as the high current required for ohmmeter operation may damage the meter. This also applies to circuits with low-filament current tubes and some types of semiconductors.
11. When measuring high resistance, be careful not to touch the test lead tips or the circuit as body resistance will shunt the circuit and give an erroneous reading.
12. Connect the ground lead of the meter first when making voltage measurements. Work with one hand whenever possible.

CONTINUITY TEST.—Open circuits are those in which the flow of current is interrupted by a broken wire, defective switch, or any means by which the current cannot flow. The test used to check for opens (or to see if the circuit is complete or continuous) is called continuity testing.

An ohmmeter (which contains its own batteries) is excellent for a continuity test. In an emergency, a continuity tester can readily be made from a flashlight. Normally, continuity tests are performed in circuits where the resistance is very low (such as the resistance of a copper conductor). An open circuit is indicated by a very high or infinite resistance. Such a condition would be an open conductor.

The diagram in figure 13-1 shows a continuity test of a cable. Notice that both connectors are disconnected and the ohmmeter is in series with the conductor under test. The power must be off. Checking conductors A, B, and C, the current from the ohmmeter will flow through plug No. 2, through the conductor, and plug No. 1. From this plug it will pass through the jumper to the chassis which is "grounded" to the aircraft's structure. The structure will serve as the return path to the chassis of unit 2 completing the circuit to the ohmmeter. The ohmmeter will indicate a low resistance.

Checking conductor D (fig. 13-1) will reveal an open. The ohmmeter will indicate maximum resistance because current cannot flow. With an open circuit, the ohmmeter needle is all the way to the left since it is a series type ohmmeter (reads right to left).

Where conditions exist that the aircraft structure cannot be used as the return path, one of the other conductors may be used. For example, to check D (fig. 13-1) a jumper is connected from pin D to pin A of plug 1 and the ohmmeter leads are connected to pins D and A of plug 2. This technique by the process of elimination will also reveal the open in the circuit.

GROUNDED CIRCUIT TEST.– Grounded circuits are caused by some conducting part of the circuit making contact either directly or indirectly with the metallic framework of the aircraft. Grounds may have many causes, the most common of which is perhaps the fraying of insulation from a wire allowing the bare wire to come in contact with the metal ground.

Grounds are usually indicated by blown fuses or tripped circuit breakers. Blown fuses or tripped circuit breakers, however, may also result from a short other than ground. A high resistance ground may also occur where sufficient current does not flow to rupture the fuse or open the circuit breaker.

In testing for grounds, the ohmmeter is used. Other continuity testers may also be used. By measuring the resistance to ground of any point in a circuit, it is possible to determine if the point is grounded. By considering figure 13-1, one possible means of testing a cable for grounds can be seen. If the jumper is removed from pin D of plug No. 1, a test for grounds is made for each conductor of the cable. This is accomplished by connecting one meter lead to ground and the other to each of the pins of one of the plugs. A low resistance will indicate that a pin is grounded. Both plugs must be removed from their units; if only one plug is removed, a false indication is possible for a conductor may be grounded through the unit.

SHORT TEST.–A short circuit, other than a grounded one, is one where two conductors accidentally touch each other directly or through another conducting element. Two conductors with frayed insulation may touch and cause a short. Too much solder on the pin of a connector may short to the adjacent pin. In a short circuit, sufficient current may flow to blow a fuse or open a circuit breaker. However, it is entirely possible to have a short between two cables carrying signals; such a short will not be indicated by a blown fuse.

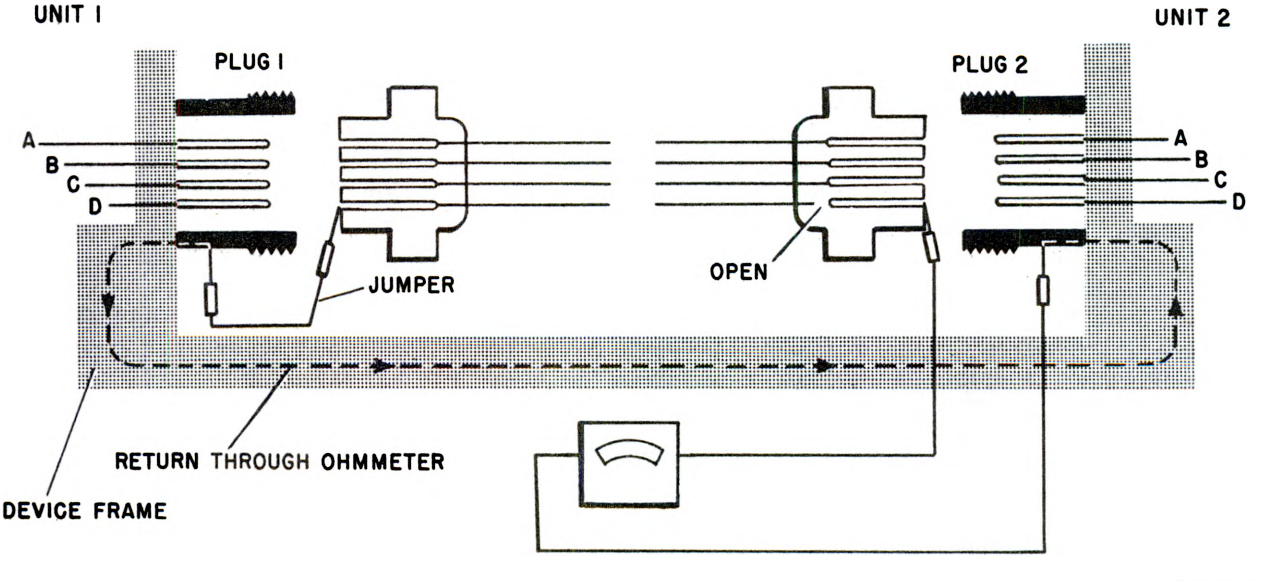

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Figure 13-1.–Continuity test.

As when checking for a ground, the device used for checking for a short is the ohmmeter. By measuring the resistance between two conductors a short between them may be detected by a low resistance reading. In figure 13-1 by removing the jumper and disconnecting both plugs, a short test may be made. This is performed by measuring the resistance between the two suspected conductors.

Shorts are not reserved for cables, they occur in many components, such as transformers, motor windings, capacitors, etc. The major test method for testing such components is a resistance measurement, and then comparing the indicated resistance with the resistance given on schematics or in maintenance manuals.

VOLTAGE TEST.–The voltage test must be made with the power applied; therefore, the prescribed safety precautions must be followed to prevent injury to personnel and damage to the equipment. The technician will find in his maintenance work that the voltage test is of utmost importance. It is used not only in isolating casualties to major components but also in the maintenance of subassemblies, units, and circuits. Before checking a circuit voltage, a check on the voltage of the power source should be made to be sure that the normal voltage is being impressed across the circuit.

BENCH PROCEDURES

The visible condition of a unit is usually the first thing to check in any process of troubleshooting. If certain parts are obviously not in proper condition, these faults must be corrected before going any further in the tests. Such conditions include parts which are burned, loose from their mountings, disconnected, dented, broken, or otherwise obviously faulty. This step should be accomplished prior to installing and connecting the unit at the test bench.

The sense of smell can be helpful in pinpointing certain troubles. A part that overheats usually gives off an odor that is readily detectable, and can sometimes be located by the odor given off. However, location of a burned part does not necessarily reveal the cause of the trouble.

In determining the cause of the trouble it is usually necessary to refer to the Service Instruction Manual. This manual will be a valuable source for constant reference when performing maintenance on electronic equipment. Few technicians are so thoroughly familiar with an electronic unit that they do not have to use the manual when performing maintenance. Chapter 4 of this training manual contains a detailed description of the information that is presented in the Service Instruction Manuals.

Signal Tracing

The following procedure is given for tracing signals in RF receivers and audio amplifiers; however, this general procedure, with modifications, can be applied to most electronic troubleshooting. In radar the frequencies are higher, the methods of signal application differ, and the output in the final stage is video (veiwed) on a scope, instead of audio (heard) from a speaker or headset. The applicable Service Instruction Manual contains detailed procedures for testing most units or circuits.

Signal tracing is a very effective method for locating defective stages in many types of electronic sets. It is especially useful when servicing sonobuoy receivers, audio amplifiers, and other equipment which normally contain no built-in meters. In signal tracing, a signal voltage (similar to that which is present under operating conditions) is taken from a signal generator and is then applied to the input of the circuit in question. The signals which result are then checked at various points in the stage, using test instruments such as vacuum tube voltmeters, oscilloscopes, output meters, or any high impedance instrument which is appropriate. (The test instrument should have high impedance so that it will not change the operation of the circuit to which it is applied.)

When using the signal tracing technique to measure a-c signals, be sure that the test instruments are adequately isolated from any d-c potentials present in the circuit. Some test instruments are equipped with special a-c probes which incorporates a capacitor in series with the input; other equipments are not so equipped. Before using any item of test equipment, the technician must familiarize himself with the characteristics and proper use of the test equipment, as well as with the equipment under test.

By signal tracing methods, the gain or loss of amplifiers can be measured; and the points of origin of distortion and hum, noise, oscillation, or any abnormal effect can be localized.

The gain measurement can be used as an example of an important method in signal tracing. By this procedure, a defective stage can be found quickly in a radio sonobuoy receiver or audio amplifiers. A signal generator, with the output attenuator calibrated in microvolts, and an output meter are used. It is helpful to have data concerning the normal gain of the various stages of the device. These data are generally found in the Service Instruction Manual for the receiver under test.

The output meter may be connected across the headset (or the voice coil of a speaker) or across the secondary of the output transformer. The output of the signal generator is applied to the grid circuit of the stage under test. The attenuator of the signal generator is then adjusted until the output meter reads a value appropriate to serve as a reference figure. The output of the signal generator is then applied to the output of the stage under test (or to the input of the next stage), and the attenuator is adjusted until the same reference value is again registered on the output meter. The gain of the stage is found by dividing the second value of the signal (taken from the calibrated attenuator) by the value of the signal applied to the input of the stage.

As an example, suppose the signal generator supplies a voltage of 400 microvolts to the grid of an IF amplifier. This voltage causes the output meter to indicate some value that can be used as a reference. When the generator signal is applied to the following grid, the signal strength must be increased (to 4,000 microvolts) to cause the output meter to indicate the same reference value. The gain of the stage is equal to

$$\frac{E_{in}\ \text{2nd stage;}}{E_{in}\ \text{1st stage}}\ \text{that is,}\ \frac{4{,}000}{400} = 10$$

If similar measurements made in the remaining stages of the receiver reveal one stage in which the gain is lower than normal or is zero, that stage can then be thoroughly checked by voltage measurement, by the resistance measurement, or by simple replacement of parts until the defective one is found.

When making stage gain measurements in receivers, the value of the applied signals must be low enough to prevent the AVC system from functioning; otherwise, the measurements will not be accurate. In the Service Instruction Manual, the recommended signal values are usually stated in terms of the reference value to be used at the output meter.

Test Probe Substitution

Using a test equipment probe with equipment other than that for which it was designed may result in considerable error. Any differences in the internal resistance of the probe and input circuitry of the equipment precludes substitution without calibration. For example, the internal resistance of a 10:1 probe is, in most cases, nine times higher than the input circuitry of the equipment. It should be noted that 2:1, 50:1, and 100:1 probes are available as well as 10:1 probes.

Test probes which are not recommended for specific equipments should not be used, because they may not have sufficient capacitive adjustment to preserve the waveshape of the observed signal. A sound rule is to use all test probes only with the equipment for which they were designed.

Voltage Checks

Voltage measurements are made at various points in the stage suspected of being at fault, and the observed voltage values are compared with the normal voltage values given in the Service Instruction Manual.

When making voltage checks for comparison with a chart, be sure to use a voltmeter with the proper ohms-per-volt rating (sensitivity). Voltmeters are connected in shunt with the circuit elements under test, resulting in circuit loading. (Circuit loading is discussed in Basic Electronics and in chapter 10 of this manual.) If the sensitivity of the test instrument is the same as that of the instrument used in making the readings on the chart, the loading effect will be the same in both cases, and the readings obtained are reliable. Another important point to remember is that if the meter sensitivity is too low, loading effect may be so severe as to prevent proper operation of an otherwise normally functioning circuit.

From this comparison, the defect can often be isolated. Voltage checks are most effective when applied within a single stage, after previous checks have been made to localize the defect. This is true because modern electronic equipment is complex, and a great deal of time is required to check all the voltages present in all the stages.

Some electronic sets have built-in meters or plugs for front panel application of meters. These meters usually work in conjunction with a selector switch, and will read values of voltage or current at designated points. A defective stage can often be isolated in this manner.

Once the defective stage is isolated, it becomes a matter of point-to-point checking to isolate the fault within the stage itself. A voltmeter will pinpoint the trouble, but it often becomes necessary to use an ohmmeter to determine the exact cause of trouble, such as shorted capacitors, open resistors or transformers, or wire grounded to chassis.

Resistance Checks

Resistance checks are similar to voltage checks except that the power is removed from the set. Resistance values are measured with an ohmmeter, and the readings are compared with the normal values given in the maintenance publications. Resistance checking, like voltage measurement, is most effective after the trouble has been isolated to a particular stage. Reliance on resistance measurement alone is too time consuming to be efficient. After the trouble has been isolated, the ohmmeter is a very useful instrument and often quickly leads the technician to the cause of the trouble.

NOTE: In order to prevent damage to the ohmmeter, always be sure that there are no voltages present in the equipment prior to beginning the resistance checks. Turn off the power switches, discharge power supply and other large capacitors, and bleed off any other residual charges in the set. Also observe proper precautions when connecting or disconnecting the ohmmeter across large inductors.

A typical example of a routine resistance check applied to a single part is the ohmmeter method of checking electrolytic capacitors. A resistance measurement is made on the discharged capacitor, using the high resistance range of the ohmmeter. When the ohmmeter leads are first applied across the capacitor, the meter pointer rises quickly and then drops back to indicate a high resistance. The test leads are then reversed and reapplied. The meter pointer should rise again—even higher than before—and again drop to a high value of resistance. The deflections of the meter are caused when the capacitor is charged by the battery of the ohmmeter. When the leads are reversed, the voltage in the capacitor adds to the applied voltage, resulting in a greater deflection than at first.

Do not leave the ohmmeter connected across an electrolytic capacitor for any appreciable period of time. Electrolytic capacitors are polarity-sensitive, and reverse polarity of voltage (even from an ohmmeter) may cause excessive current which could result in overheating and possible explosion of the capacitor.

If the capacitor is open-circuited, no deflection will be noted. If the capacitor is short-circuited, the ohmmeter indicates zero ohms. The resistance values registered in the normal electrolytic capacitor result from the fact that there is some current leakage between the electrodes. Because the electrolytic capacitor is a polarized device, the resistance is greater in one direction than the other.

Should a capacitor indicate a short circuit, one end of it must be disconnected from the circuit and another resistance reading taken to determine if the capacitor is actually at fault.

Unless the ohmmeter has a very high resistance scale the deflection of the meter when checking small capacitors will not be noticeable. Even a scale of R x 10,000 is not sufficient for very small capacitors; the smaller the capacity the less leakage across the plates, therefore the more resistance.

When making resistance checks, be sure to determine what circuits are connected to the points where the checks are made. The Service Instruction Manual will indicate what resistance should be found at various checkpoints throughout the set, and will contain a complete schematic of the set as well as a circuit schematic of the stage under test. The schematics may set up conditions under which voltage and resistance measurements are to be made, such as positions of switches and control knobs, relays energized or deenergized, tube in socket, etc. These conditions will duplicate the conditions under which the measurements were first made. A typical condition might be: "Power switch OFF–all controls on the control box fully CCW (counterclockwise)." It is important that these instructions be followed to obtain accurate values to compare with specified values. Otherwise incorrect values may be obtained.

Defective Components

Before replacing a defective part it is necessary to determine if such an operation may be performed by the unit or squadron. This is determined by the level of maintenance that has been assigned to the squadron. Increasing complexity and compactness of electronic equipment have resulted in a trend toward replacement of subassemblies rather than individual parts. This trend is caused by the necessity of exact parts replacement, and the difficulty of working in small spaces where even the amount of solder used on a connection can be of importance. However, there are many parts that may be replaced at any level of maintenance. The general rule is to replace any defective part with an exact duplicate.

Publications may be consulted to aid in obtaining information (such as stock number and description) about a particular part. The publications which will most often be used when ordering parts are the IPB and the Section R list for the particular equipment under repair. Chapter 4 of this training manual explains the use of the IPB and the Section R lists, and also the Standard Aeronautical Electronics Material Section R, NavWeps 00-35QR-4.

Should it become necessary to replace a part with a substitute, the technician must make sure that the substitute part is a proper replacement. With resistors, for instance, several characteristics must be considered–ohmic value, wattage rating, tolerance, physical size, and type of construction. Capacitors involve consideration of physical size, capacity, tolerance, temperature coefficient, and voltage rating. Plugs and connectors will almost invariably have to be exactly as prescribed since it is difficult to find items of this type that are interchangeable. Familiarity with the IPB is a definite asset to the technician who must determine exactly what part to order.

Basic Electronics contains information on color codes for capacitors and resistors. Refer to this manual for information on standard codes, specifications, physical shapes, methods of reading, and tolerances.

Checking After Repair

No repair job is complete until the repaired unit or set is reinstalled and actually operating properly. The set must be bench checked after the trouble is remedied, usually before the set is completely reassembled, and any alinement adjustments necessary to assure proper operation should be made. After reassembly of the set–replacement of dust and shielding covers, installation of set in outer case (and pressurization if necessary)–a final bench operational check should be performed. Oftentimes a shield or plate that has been installed will touch a bare wire or other contact and will render the set inoperative, or cause substandard operation. It is much better to discover such a fault at the bench than in the aircraft.

After the set is reinstalled in the aircraft and properly secured for flight, it must be given a final operational test. It cannot be assumed that because the set operated properly on the bench it will do so in the aircraft. The most important test is an operational check under exact operating conditions. When the set performs properly in the aircraft and is securely mounted, the discrepancy sheet may be signed. This signature indicates that the electronic set should operate properly under normal flight conditions.

The troubleshooting information described in the preceding paragraphs is summarized in figure 13-2, which shows in chart form a general troubleshooting procedure. The directions given in blocks 1 through 5 are steps to be used in locating trouble, and the directions given in blocks 6 and 7 are steps in repairing the set. (Steps 2, 3, 4, and/or 5 may sometimes be eliminated, but steps 6 and 7 will always be followed.)

REPAIR INFORMATION

As was mentioned previously, increasing complexity and compactness of electronic equipment have caused a trend toward replacement of subassemblies rather than individual parts. This trend is caused by the necessity of exact parts replacement, and the difficulty of working in small spaces where even the amount of solder used on a connection can be of importance. However, there are many parts that will need to be replaced, and the rule is to replace a defective part with an exact duplicate.

The trend toward replaceable units has led to several new methods of construction of electronic equipment. Two examples are MICROELECTRONICS and PRINTED CIRCUITS. These circuits are designed for speed and economy of manufacture, and speed and ease of maintenance, as well as saving of space and weight.

SOLDERING

Soldering operations are a vital part of electronics maintenance procedures. It is a manual skill which can and must be learned by all personnel assigned electronics maintenance shop duties. Practice is required to develop proficiency in the techniques of soldering; however, practice serves no useful purpose unless it is founded on a thorough understanding of basic principles. This discussion is devoted to providing information regarding some important aspects of soldering operations.

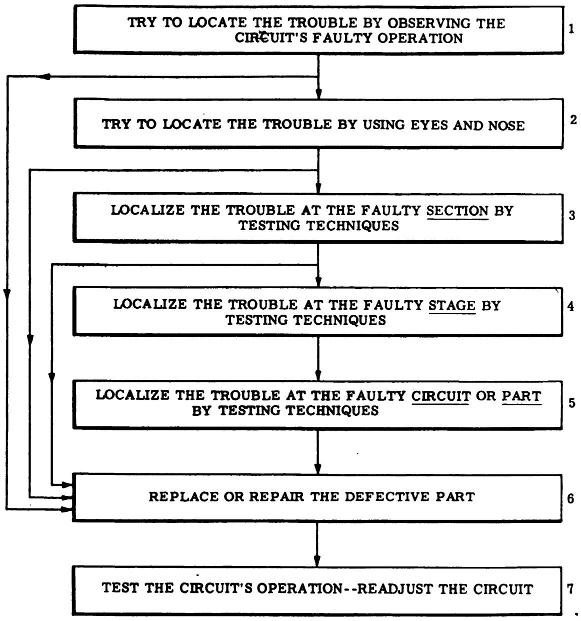
TRY TO LOCATE THE TROUBLE BY OBSERVING THE CIRCUIT'S FAULTY OPERATION
1
TRY TO LOCATE THE TROUBLE BY USING EYES AND NOSE
2
LOCALIZE THE TROUBLE AT THE FAULTY SECTION BY TESTING TECHNIQUES
3
LOCALIZE THE TROUBLE AT THE FAULTY STAGE BY TESTING TECHNIQUES
4
LOCALIZE THE TROUBLE AT THE FAULTY CIRCUIT OR PART BY TESTING TECHNIQUES
5
REPLACE OR REPAIR THE DEFECTIVE PART
6
TEST THE CIRCUIT'S OPERATION--READJUST THE CIRCUIT
7

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Figure 13-2.–Troubleshooting procedure.

Soldering Iron

Proper preparation of the soldering iron is essential. The iron to be used should be selected on the basis of heat required. A 100-watt iron is satisfactory for splices and terminals; a 30-watt iron should be used for repair of printed circuits.

The tip must be free of oxide, scale, and carbonized flux, and should be smooth and completely tinned prior to use. Solder dissolves copper gradually, causing pits in the tip. Such pits should be filed smooth and the tip retinned.

During use, periodically wipe the tip to remove excess solder and flux.

Temperature

Both the solder and the material to be soldered must be heated to a temperature which allows the solder to flow. If either is heated inadequately, "cold" solder joints result. Such joints do not provide either the physical strength or the electrical conductivity required. Appreciably exceeding the flow point temperature, however, is likely to cause damage to the parts being soldered. Various types of solder flow at different temperatures. In soldering operations it is necessary to select a solder that will flow at a temperature low enough to avoid damage to the part being soldered, or to any other part or material in the immediate vicinity.

The duration of high heat conditions is almost as important as the temperature. Insulation and many other materials in electronic equipment are susceptible to damage from heat. They are damaged if exposed to excessively high temperatures, or deteriorate if exposed to less drastically elevated temperatures for prolonged periods. The time and temperature limitations depend on many factors–the kind and amount of metal involved, the degree of cleanliness, the ability of the material to withstand heat, and transfer and dissipation characteristics of the surroundings.

Soldering Process

Cleanliness is a prime prerequisite for efficient, effective soldering. Solder will not adhere to dirty, greasy, or oxidized surfaces. Heated metals tend to oxidize rapidly, and the oxide must be removed prior to soldering. Oxides, scale, and dirt can be removed by mechanical means (such as scraping or cutting with an abrasive) or by chemical means. Grease or oil films can be removed by a suitable solvent. Cleaning should be accomplished immediately prior to the actual soldering operation.

Items to be soldered should normally be tinned before making mechanical connection. When the surface has been properly cleaned, a thin, even coating of flux may be placed over the surface to be tinned to prevent oxidation while the part is being heated to soldering temperature. Rosin core solder is usually preferred in avionic work, but a separate flux may be used instead. Separate flux is frequently used when tinning wires in cable fabrication. Acid core solder or acid flux should be avoided due to its corrosive action.

The tinning on a wire should extend only far enough to take advantage of the depth of the terminal or receptacle. Tinning or solder on wires subject to flexing causes stiffness, and may result in breakage.

The tinned surfaces to be joined should be shaped and fitted, then mechanically joined to make good mechanical and electrical contact. They must be held still with no relative movement of the parts. Any motion between parts will likely result in a poor solder connection.

SOLDERED CONNECTIONS.–Frequent arguments occur in electronics maintenance shops concerning the proper method of making soldered connections to terminals and binding posts. For many years it was considered necessary to wrap the lead tightly around the terminal, so as to provide maximum mechanical support and strength. According to MIL-S-6872, General Specification for Soldering Process, "The parts to be joined shall be held together in such a manner that the parts shall not move in relation to one another during the soldering process. The joint shall not be disturbed until the solder has completely solidified."

The Navy Electronics Laboratory tested many standard capacitors and resistors soldered to terminals of various types. The joints were then subjected to vibrations far in excess of those encountered in military ships, aircraft, and armored vehicles. The connections were made with various degrees of wrapping around the terminals, with main reliance for physical strength being placed on the solder. As a result of this test and other conducted by other organizations, the joints illustrated in figure 13-3 are recommended. Wrappings of three-eights to three-fourths turn are usually recommended so that the joint need not be held during the application and cooling of the solder.

Excessive wrapping of leads results in increased heat requirements, more strain on parts, greater difficulty of inspection, greater difficulty of assembly and disassembly of the joints, and increased danger of breaking the parts or terminals during desoldering operations. Insufficient wrapping may result in poor solder joints due to movement of the lead during the soldering operation.

The areas to be joined must be heated to or slightly above the flow temperature of the solder. The application of heat must be carefully controlled to prevent damage to components of the assembly, insulation, or nearby materials. Solder is then applied to the heated area. Only enough solder should be used to make a satisfactory joint. Heavy fillets or beads must be avoided.

Solder should not be melted with the soldering tip and allowed to flow onto the joint. The joint should be heated and the solder applied to the joint. When the joint is adequately heated, the solder will flow evenly. Excessive temperature tends to carbonize flux, thus hindering the soldering operation.

No liquid should be used to cool a solder joint. By using the proper tools and soldering technique, a joint should not become so hot that rapid cooling is needed.

If, for any reason, a satisfactory joint is not initially obtained, the joint must be taken apart, the surfaces cleaned, excess solder removed, and the entire soldering operation (except tinning) repeated.

After the joint has cooled, all flux residues should be removed. Any flux residue remaining on the surface of electrical contacts may collect dirt and promote arcing at a later time. This cleaning is necessary even when rosin-core solder is used.

Connections should never be soldered or desoldered while equipment power is on or while the circuit is under test. Always discharge any capacitors in the circuit prior to any soldering operation.

MICROMAINTENANCE

Microelectronic technology by itself will not solve the maintenance problem. In spite of the greatly increased reliability, failures will still occur. When they do, the faulty items must be isolated and repaired or replaced.

With the discrete miniature component (transistor, resistor, capacitor, etc.), the maintenance technician can test individual circuit elements and thus determine the cause of failure. Repairs can then be made by replacing the faulty component.

With the integrated circuit, replacement of an individual part is impossible because the unit is designed and exists only as a complete functional element. The maintenance process then becomes a matter of isolation and replacement of the defective "chip," "flat-pack," board, or module.

Modules

Modular assemblies are mechanically more rugged than conventional circuits. They are, however, susceptible to damage from improper handling, electrical overload, or overheating. Techniques of maintenance and servicing are similar to those used with conventional circuits, but require somewhat more care in execution.

The small size and close spacing of the parts within the assembly require more care and smaller tools than are normally required in conventional maintenance. Additional devices and maintenance aids are of great help in developing the precision needed for such close work. Many components are inherently susceptible to damage from various causes. These factors require modification of some of the basic maintenance techniques and the use of some new ones.

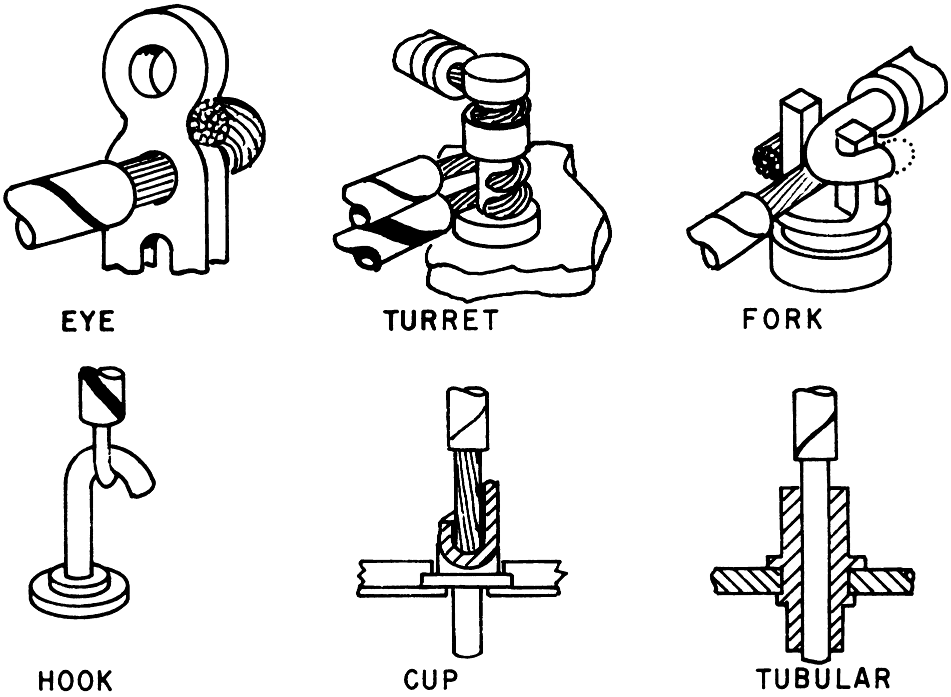

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Figure 13-3.–Wrapping of terminals for soldering.

Component damage during maintenance is usually the result of excess heat during repair, reversed polarity of ohmmeters while checking for continuity, application of excessive voltages or signal magnitudes during testing, rough handling, or use of the wrong tools or materials.

Loosening connections, disconnecting parts, inserting or removing transistors, and changing modular units should not be done with the power on or while the circuit is under test. These actions (or a loose connection of any type) will cause an inductive kickback, which may damage the component.

It is also important to remove any capacitive charge from parts, tools, or test equipment before connecting them to any modular unit. A grounding clip should be connected from the item to the modular chassis before making any other contact. When disconnecting, the grounding clip should be removed last.

Leads to transistors, printed circuit boards, etc., as well as many miniature components are easily damaged in handling, stowage, or shipping. Proper precautions should be used at all times.

It should be emphasized that these miniature components and circuits can be repaired, if adequate care and proper techniques are used.

Maintenance Aids

In maintenance of microcircuits special devices are needed to extend the vision, aid the reach, and act as a third hand for the technician. Special tool and device requirements depend on the equipment to be serviced and on the maintenance operations involved. Many of the tools and devices discussed in this section are useful in all maintenance activities; others have limited applicability. The assortment of tools should be kept to the minimum required for effective and efficient maintenance of assigned equipment. A few useful special tools are shown in figure 13-4.

Many dental implements no longer usable for their original purpose can be readily adapted for use by the technician. These include various knives for scraping protective coatings and excess solder, brushes for cleaning, probes and mirrors for inspecting in crowded spaces, and drills for making small repairs. Tweezers and surgical hemostats are useful for grasping and holding small parts. Although they may also be used as heat shunts in soldering, their effectiveness is limited. A more desirable heat shunt is described later in this section. Hypodermic syringes (not shown) are useful in oiling hard-to-reach points.

A pin vise is useful in drilling through plastic, bakelite, or the copper-ribbon conductor strips of a printed circuit board. It may also be used to clean solder from hollow receptacles and terminals. In addition, it can hold many sizes and shapes of hooks and probes made from spring wire. These attachments are useful in inspection and servicing in confined spaces.

A magnifying device for inspecting minute parts is essential. If the magnifier is mounted on a stand it leaves the technician with both hands free for other tasks.

When working on a printed circuit or terminal board which has been removed from its mounting, the work must be held firmly. An easily built device suitable for this purpose is the jig shown in figure 13-5. The jig will provide support and prevent flexing or slipping. Securing the jig to the worktable leaves the technician with both hands free during the maintenance process.

For any desoldering operation, the part should be mounted so that the terminals are pointed out and downward. Place the soldering iron under the terminals so the solder flows away from the joint. To resolder the joint, invert the part.

A drawer or box with a white cloth can be used to catch any small parts dropped during maintenance. A drawer and sheet (or a cigar box and handkerchief) should prove adequate. (See fig. 13-6) in attaching the cloth, leave a little slack to form a pocket in the middle. When the jig (fig. 13-5) is mounted immediately above the trap any part dropped should find its way to the center of the cloth.

PRINTED CIRCUITS

Although maintenance procedures for printed circuits are similar to those for other circuits, they require more skill and care. Any defective part should be pinpointed by careful analysis of the symptoms before attempting to trace trouble on a printed circuit board.

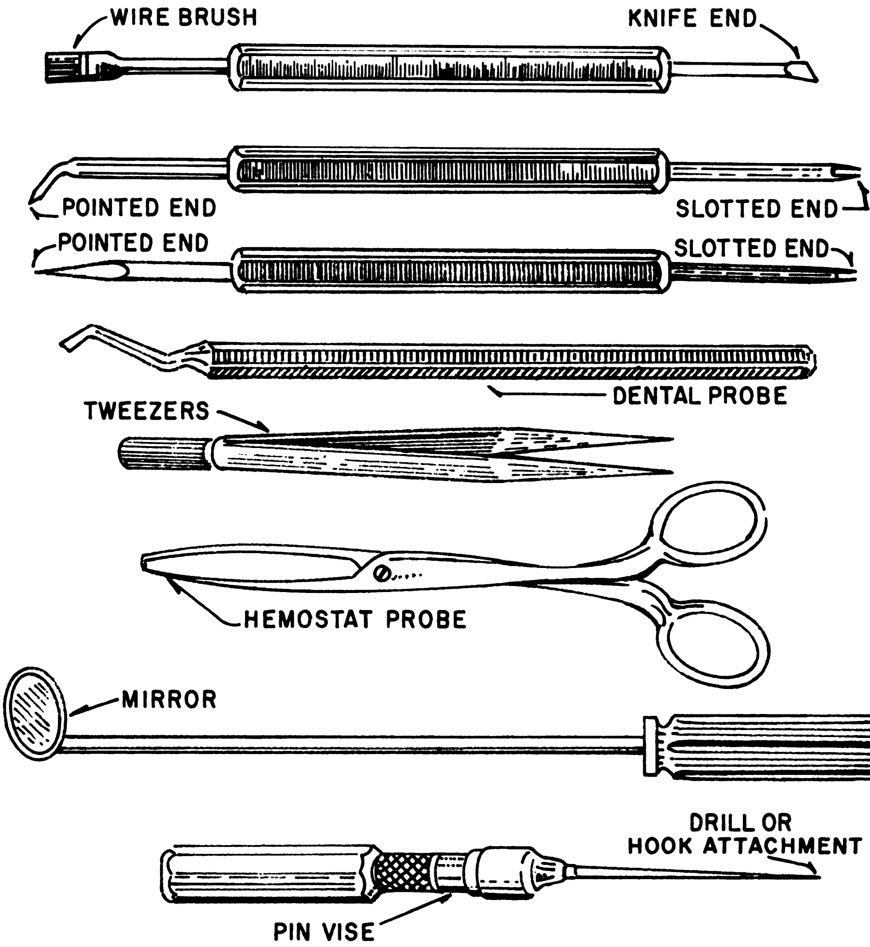

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Figure 13-4.—Special tools.

Breaks in the conducting foil strip can cause either permanent or intermittent trouble. When searching for a break in the foil, first determine whether the strips have a protective coating. If so, it will be necessary to penetrate this film when checking for continuity. A needlepoint probe works very nicely.

Use a multimeter or an ohmmeter for checking continuity. Use a meter that passes no more than one milliampere. If the circuit contains transistors or other semiconductors, observe proper biasing conditions.

First check for continuity from one end to the other of each strip (being sure to penetrate the protective coating, but being careful not to damage the strip). If an open is indicated, move the probes one at a time until continuity is indicated. The break then lies between the last two positions of that probe. Carefully inspect the break to determine its extent and the repair process needed.

If the break is small, carefully scrape away any protective coating, clean the area with a firm bristle brush and an approved solvent, and flow solder over the break as indicated in figure 13-7 (A). If there is any indication that the strip might peel loose from the board, bridge the break with a small section of bare wire as indicated in figure 13-7 (B). Apply solder along the entire length of the wire to bond it firmly to the

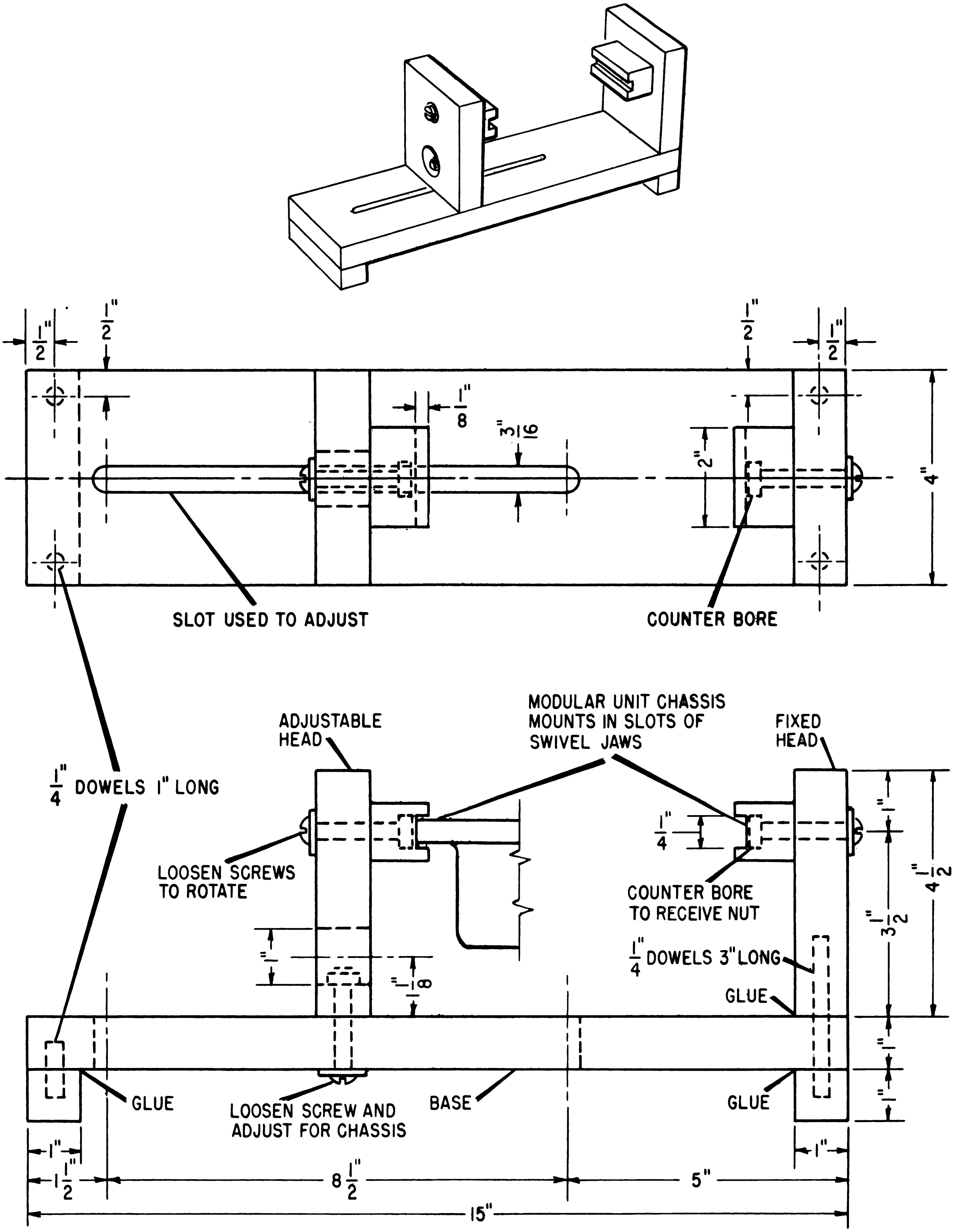

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Figure 13-5.–Jig for holding terminal boards.

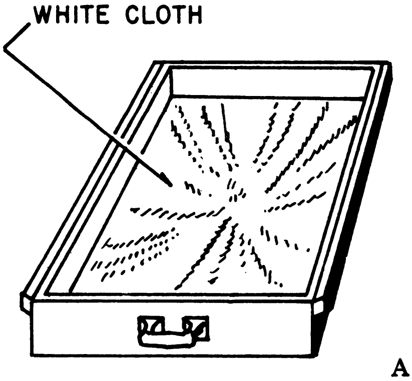

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Figure 13-6.—Trap for catching dropped parts.

conducting strip. Keep the solder within the limits of the strip being repaired, to prevent the solder from flowing onto or near an adjacent strip. Be careful not to overheat any part of the area.

If a strip is burned out or fused, cut and remove the damaged strip and replace it with a wire soldered from terminal to terminal on the board.

A printed circuit board can withstand only a limited amount of flexing. Excessive flexing results in a broken board, which must then be replaced. When working on a board which is still mounted in its normal location, never use pressure. When the board is removed from its mounting, use the jig described earlier, and never use pressure.

After repairs are completed, thoroughly clean the board, restore the protective coating, and allow to dry thoroughly before reinstalling or applying power to the circuit.

Removal of transistors, tube sockets, or other parts from a printed circuit board often requires the simultaneous movement of several soldered connections. For this purpose use the pencil type soldering iron and special tips when possible. Remove excess solder from each connection, using a scribe or needle probe to scrape away the solder. Do not rock or pry the part to loosen the connection—rocking may damage the board. When all connections are free, simply lift the part.

To install the replacement part, solder each connection separately, in turn.

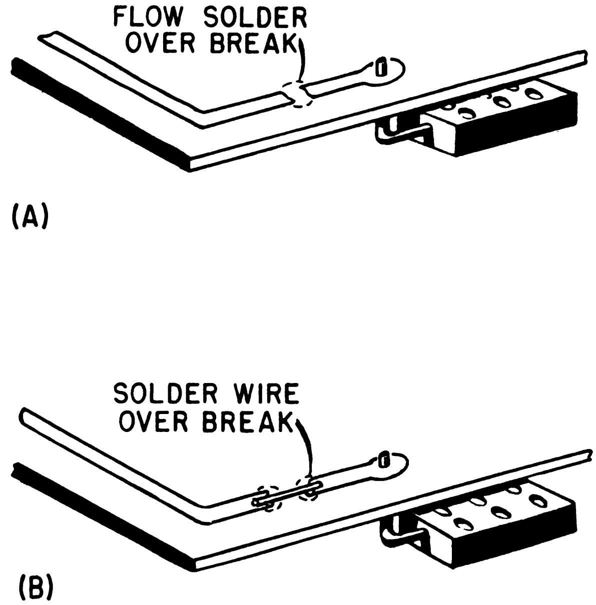

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Figure 13-7.—Repairing breaks in foil.

SEMICONDUCTORS

Transistors, unlike vacuum tubes, are very rugged in that they can tolerate vibration and a rather large degree of shock. Under normal operating conditions they will give dependable service over a long period of time. However, transistors are subject to failure when subjected to even minor overloads. Crystal detectors are also subject to failure or deterioration when subjected to electrical overloads; in addition they will deteriorate from long periods of normal use.

In order to determine the condition of semiconductors, various test methods can be used. In many cases it is possible to substitute a transistor known to be good for a questionable one; and thus determine the condition of a suspected transistor. This method of test is highly accurate and sometimes expeditious. However, indiscriminate substitution of semiconductors in critical circuits is to be avoided. When transistors are soldered into equipment, substitution becomes impracticable; it is generally desirable to test these transistors in their circuits.

Since certain fundamental characteristics are an indication of the condition of semiconductors, test equipment is available for determining these characteristics with the semiconductor both in and out of their circuits. Crystal-rectifier testers normally test only the forward and reverse current ratio of the crystal. Transistor testers are capable of measuring several characteristics, such as the leakage current (I_{CO}), the current gain (beta), and the four-terminal network parameters. The most useful characteristic for test purposes is determined by the type of circuit in which the transistor will be used. The beta measurement is preferred for a-c amplifiers or oscillator applications. For switching-circuit applications, a direct-current measurement may be more useful.

Semiconductor Designation

Semiconductors are designated by the use of number and letter combinations that have been accepted as standard. The first number indicates the number of junctions and the letter "N" indicates a semiconductor. The number following the letter indicates the registration order. An example is the 1N21B. The "1" preceeding the "N" indicates a diode. The "N" indicates a semiconductor. The 21B indicates the 21st registration and the "B" indicates a modification of a 1N21A semiconductor.

Transistors also are identified by the number-letter-number sequence, that is, a 2N130 would be a triode transistor, registration number 130. Even though the above information is considered to be standard, different manufactures will sometimes use their own numbering system.

Semiconductor Basing and Basing Diagrams

Diodes have only two leads and a dot or color indicates the cathode terminal. Transistor leads generally have a color dot to indicate the collector lead or the collector is spaced farther from the other leads. The lead farthest from the collector, in line, is usually the emitter and the base lead is between the collector and emitter leads. This is shown in figure 13-8 (A). When the leads are evenly spaced, a red dot indicates the collector, as shown in figure 13-8 (B). If the base is circular, a red line indicates the collector and the emitter lead is the shortest lead. This is shown in figure 13-8 (C). In figure 13-8 (D), the triangular arrangement is off-set and the lead opposite the blank quadrant is the base lead. The collector is the first lead clockwise from the base. In power transistors, the collector lead is usually connected to the mounting base and the emitter lead will be identified by a color, as shown in figure 13-8 (E). One method of identifying leads of tetrode type transistors is shown in figure 13-8 (F).

Whenever a doubt exists regarding a particular type of semiconductor, a transistor manual or manufacturer's specification sheet should always be consulted.

SEMICONDUCTOR MEASUREMENTS

Because of the reliability of semiconductor devices, servicing techniques developed for transistorized equipment differ from those normally used for vacuum tube circuits. Vacuum tubes are usually considered to be the circuit component most susceptible to failure, and are therefore, normally the first components to be tested. Transistors are capable of operating in excess of 30,000 hours at maximum rating without appreciable degradation, and are often soldered into the equipment in the same manner as resistors and capacitors.

Substitution Test

Substitution of a crystal diode or transistor, known to be in good condition is a simple method of determining the quality of a questionable semiconductor device. This technique should be used only after voltage and resistance measurements are made to insure that there is no circuit defect that might damage the substituted semiconductor device. If more than one defective semiconductor is present in the equipment section where trouble has been localized, this method becomes cumbersome, since several semiconductors may have to be replaced before the trouble is corrected. To determine which stage failed and which semiconductors are not defective, all of the removed semiconductors must be tested. This can be accomplished by observing whether the equipment operates cor-

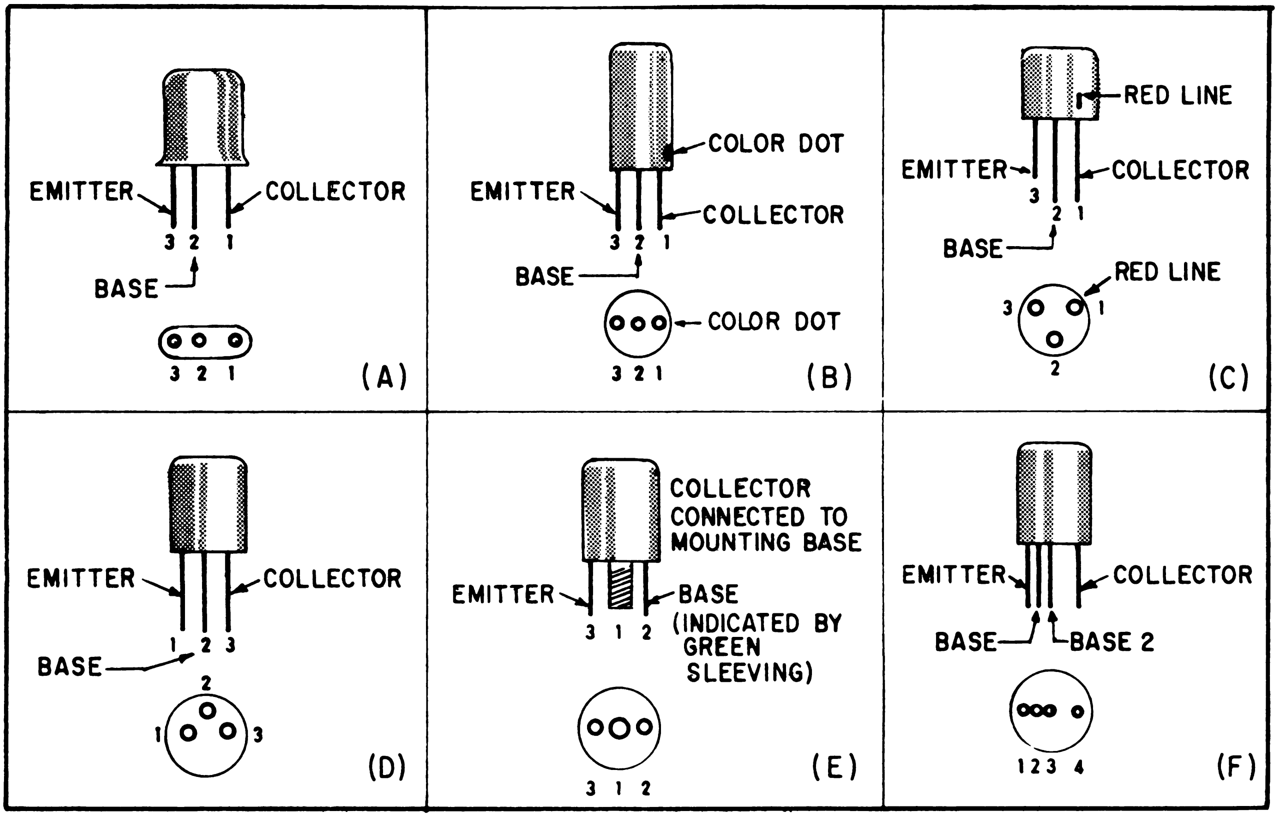

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Figure 13-8.—Transistor lead identification.

rectly as each of the removed semiconductor devices is reinserted into the equipment.

TRANSISTOR MEASUREMENTS

When trouble occurs in transistorized equipment, power supply voltage measurement, waveform checks, signal substitution or tracing methods are normally the first tests made. If a faulty stage is isolated by one of these test methods, voltage, resistance, and current measurements can be made to locate the defective part. When making these measurements care must be taken to make certain that the voltmeter resistance is high enough to have no appreciable effect upon the voltage being measured, and that the current from the ohmmeter will not damage the transistor. If the transistors are not soldered into the equipment, it is usually advisable to remove the transistors from their sockets during resistance tests. Transistors should be removed from or reinserted into their sockets only after power has been removed from the stage, since damage by surge current may otherwise result.

Transistor circuits other than pulse and power amplifier stages are usually biased so that the emitter current is in the vicinity of 0.5 to 3 milliamperes and the collector voltage is 3 to 15 volts. The emitter current can be measured by opening the emitter connector and inserting a milliammeter. When making this measurement, some change in bias should be expected due to the meter resistance. The collector current can often be determined by measuring the voltage drop across a resistor in the collector circuit and calculating the current by ohms law. If the transistor itself is suspected, it can be tested by the method described previously.

Resistance Test

An ohmmeter can be used to test transistors by measuring the emitter-collector, base-emitter, and base-collector forward and back resistances. Check the ohmmeter handbook to determine the polarity of the test leads. Some models apply reverse voltage from the internal battery.

CAUTION: Any ohmmeter used which is capable of delivering current in excess of 1 millampere may damage the transistor. USE ONLY AN APPROVED TYPE OHMMETER.

A back-to-forward resistance ratio on the order of 500 to 1 should be obtained for the collector-to-base and emitter-to-base measurements. The forward and back resistances between the emitter and collector should be nearly equal. All three measurements should be made for each transistor tested, since experience has shown that transistors can develop shorts between the collector and emitter and still have good forward and back resistance for the other two measurements.

Because of shunting resistances in transistor circuits, it will normally be necessary to disconnect at least two transistor leads from the associated circuit for this test. Caution must be exercised during this test to make certain that current during the forward resistance tests does not exceed the rating of the transistor.

HANDLING TRANSISTORS

Transistors, although generally more rugged mechanically than vacuum tubes, are susceptible to damage by excessive heat and electrical overload. The following precautions should be taken in servicing transistorized equipment:

1. Test equipment and soldering irons must be checked to insure that there is no leakage current from the power source. If leakage current is detected isolation transformers must be used.
2. Ohmmeter ranges which require a current of more than 1 milliampere in the test circuit should not be used for testing transistors.
3. Battery eliminators should not be used to furnish power for transistor equipment because they have poor voltage regulation and, possible, high ripple voltage.
4. The heat applied to a transistor, when soldered connections are required, should be kept to a minimum by using a low-wattage soldering iron and heat shunts, such as long-nose pliers, on the transistor leads between the iron and the transistor.
5. All circuits should be checked for defects before a transistor is replaced.
6. The power should be removed from the equipment before replacing a transistor or other circuit part.
7. When working on equipment with closely spaced parts, conventional test probes are often the cause of accidental short circuits between adjacent terminals. Momentary short circuits, which rarely damage a vacuum tube, may ruin a transistor. To avoid accidental shorts the test probes can be covered with insulation for all but a very short length of the tips.

SERVICING SEMICONDUCTOR CIRCUITS

Most new circuit design is based on the use of semiconductors. While some devices operate safely at high temperatures, the majority of transistors and crystal diodes in present use are particularly sensitive to temperature.

When transistors are mounted in sockets, they should be removed from the sockets before beginning any soldering operations on the terminals. Some transistors and most crystal diodes in printed circuits, however, are soldered directly in place. All connections must be desoldered before the semiconductor can be removed. Semiconductors cannot safely withstand the heat produced even with the pencil soldering iron. It is necessary, therefore, to use a heat shunt.

The soldering gun should not be used to solder or desolder semiconductor components in equipment. The strong electromagnetic field produced by the gun may cause induced currents great enough to damage the component.

Even conventional irons should be grounded to the chassis of transistorized equipment under repair, as mentioned previously, to prevent damage from accumulated electrical charges.

Semiconductors and many other miniature components are extremely susceptible to damage from electrical overloads. The maximum ratings for components are usually given in the technical manuals and in the charts and tables supplied for each equipment or major component. These ratings should not be exceeded.

Transistors and similar components require various power supply connections. When preparing a unit for operation on the test bench or in a breadboard type hookup, check the voltages and their polarities against the tables and drawings before activating the power. When using an ohmmeter for continuity testing, check the range and short circuit current rating of the meter before attaching it to the transistor.

Reversing the plate voltage on a triode vacuum tube will generally keep the tube from operating, but will normally not damage the tube. Semiconductors, however, are polarity-sensitive. Reversing the collector voltage polarity of a transistor or other semiconductor may ruin it instantly and permanently.

Leakage current from test equipment to the modular unit can also destroy transistors and other semiconductors. To prevent this, the use of an insolation transformer is recommended for those test sets which do not operate with transformer supplies to produce their operating voltages. In any event, the use of a grounding strap is recommended for all test equipments and instruments used in servicing or testing these circuits. The ground should be connected first to the module chassis, then to the test equipment ground post or chassis.

High magnitude pulses will also destroy transistors. Test equipment should be connected with minimum output or maximum attenuation settings, and gradually adjusted to the desired level.

TERMINAL BOARDS

It is often possible to replace a defective resistor or capacitor without removing the board from the chassis. If the leads extending from the defective component are long enough for a replacement part to be soldered to them, they may be cut where they enter the defective component. If the leads are not long enough, it is possible to get extra length by the method shown in figure 13-9. Cut the part in half and crush each half to take advantage of the lead length within the part. Make a hook in the remaining length of lead, then connect the new part.

When any soldering operation is necessary, use the pencil iron and its special tips, or the improvised tips described previously, with a ground lead connected from the tip of the soldering iron to the chassis of the part. Usually it is more convenient, and it is always safer, to completely remove the module and work on an insulated surface, using a jig.

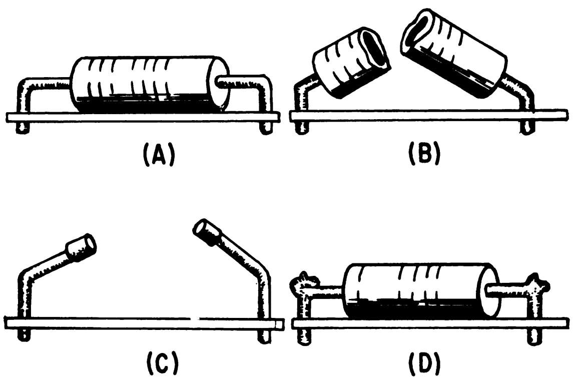

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Figure 13-9.—Replacing resistor.

Any part to be removed should never be pried or forced loose. Any attempt to force a part loose may result in a broken or separated printed circuit panel. If the terminals do not pass easily through their holes, chances are that all the solder has not been removed. If any solder is left in the terminal hole after removing the leads, apply the soldering iron to the hole just long enough to soften the solder, and then gently poke the softened solder out with a toothpick, scribe, or small brush; or if necessary use a pin vise and drill.

RESISTORS

When a resistor must be replaced, one of the important considerations in selecting the replacement is the wattage value. In general, the wattage rating is a measure of the ability of the resistor to dissipate heat, and the value is related to the physical size of the resistor.

The selection of a safe wattage value is based on a consideration of the working conditions of the resistor in the circuit. Consider as an example the replacement of an 850-ohm resistor with one of equal ohmic value but which has a tolerance of ±20 percent. Suppose the normal voltage existing across the resistor is 40 volts. Because of the 20 percent tolerance, the actual resistance of the replacement may be as much as 1,020 ohms or as little as

680 ohms. Taking the lesser value (the more unfavorable from a heat-dissipating standpoint), the power that may be developed in the resistor under circuit conditions is found as follows:

$$W = \frac{E^2}{R}$$

$$W = \frac{40 \times 40}{680}$$

$$W = 2.35 \text{ watts, approximately}$$

A resistor should be capable of dissipating from 1.5 to 2 times the power actually encountered, to allow sufficient margin of safety. In the example, this value is not more than 4.7 watts. Since a 5-watt resistor is the next standard size above the 4.7-watt value, this is a desirable wattage rating for the replacement.

Under emergency conditions, it is sometimes necessary to combine resistors in series or in parallel to obtain a desired resistance value. When this is done, care should be taken to avoid a voltage distribution (or current distribution) which causes any low-wattage resistor in the combination to dissipate an excessive amount of heat. For example, suppose two 10-watt resistors of 1-ohm value were combined in series with a 2-watt resistor of 10 ohms. The total wattage dissipated when the series combination is connected across 12 volts is 12 watts. But the power dissipated by the 10-ohm, 2-watt resistor is 10 watts, a value far in excess of its capabilities. It is necessary to consider each resistor in the combination and select a wattage value based on the voltage developed across the individual unit.

AIRCRAFT AND EQUIPMENT WIRING

Wiring in aircraft normally runs from point to point, or plug to plug, without interruption (no splices). However, there are methods of splicing wires in aircraft that are acceptable as permanent splices.

Wiring in aircraft is identified by a system of numbers and letters stamped on each wire, as described in chapter 4 of this manual. The Service Instruction Manual and the Maintenance Instructions Manual give the number of each wire involved in cabling of electronic equipment. Should it become necessary to trace and repair a wire in the aircraft, refer to these manuals to determine the routing of the wire involved.

Wiring data for all electrical and electronic systems in each model aircraft are contained in the Wiring Data section of the applicable Maintenance Instructions Manual. The diagrams are prepared separately for each circuit and provide all data necessary to understand the construction of each circuit, to trace each circuit within the system, to make continuity and resistance checks, and to perform specific troubleshooting on inoperative or malfunctioning circuits. Schematic diagrams for circuits and related components are found in those volumes of the Maintenance Instructions Manuals specifically covering a system or systems.

An excellent source of information in connection with power distribution and aircraft wiring is Installation Practices for Aircraft Electric and Electronic Wiring, NavWeps 01-1A-505. This manual presents the recommended practices and techniques to be used for installing, repairing, and maintaining aircraft electric wiring. It includes information under the following headings: Wire and cable preparation; general-purpose connectors; RF connectors and cabling; solderless terminations and splicings; thermocouple wire soldering and installation; bonding and grounding; bus bar preparation; conduit fabrication; installation of bus bars, conduit, junction boxes, protective devices, and terminal strips; electrical wiring installation; lacing and tying; safety wiring; and emergency repairs. This information is summarized in the following paragraphs. Refer to the manual for additional details.

CONNECTORS

In the discussion which follows, the word "connector" is used in a general sense. It applies equally well to connectors designated by "AN" numbers and those designated by "MS" numbers (fig. 13-10 (A)). AN numbers were formerly used for all supply items cataloged jointly by the Army and Navy. Many items, especially those of older design, continue to carry the AN designator, even though the supply system is shifting over to MS (Military Specification) numbers.

AN specification numbers for connectors have been generally superseded by MS numbers. However, many instances will occur in which connectors are still referred to as "AN connectors."

Inspection

Connectors are inspected when the major units that they connect are inspected. During this inspection, the mating parts of the connectors are separated and the contacts examined for corrosion. If corrosion is present, the surfaces are cleaned with a brush or clean rag and a noncorrosive solvent. The coupling ring is inspected for battered threads, and should be replaced if the threads are not in good condition. When attaching or detaching the connector, care should be taken to avoid damaging the coupling or bending the coupling nut. (See fig. 13-10(B).)

If the connector does not contain a moistureproofing compound, the conductors should be inspected where they are soldered to the pin contacts. Short circuits are often caused by a frayed strand of one conductor touching the solder cup of another conductor within the plug. If this is the case, the frayed strand may be clipped. Check to see that all soldered connections are adequate and that no cold solder joints exist.

Connectors do not require lubrication except for the coupling ring threads. Occasionally, they should be given a light coat of antiseize compound to insure smooth operation.

Maintenance

At times, operating conditions demand that ordinary electrical connectors be given a moistureproofing treatment. The basis of moistureproofing is the application of a sealing compound.

Moistureproofing reduces failure of electrical connectors and reinforces the wires at the connectors against failure caused by vibration and lateral pressure, both of which fatigue the wire at the solder cup.

The sealing compound also protects electric connectors from corrosion and contamination by excluding metallic particles, moisture, and aircraft liquids. As a result of its improved

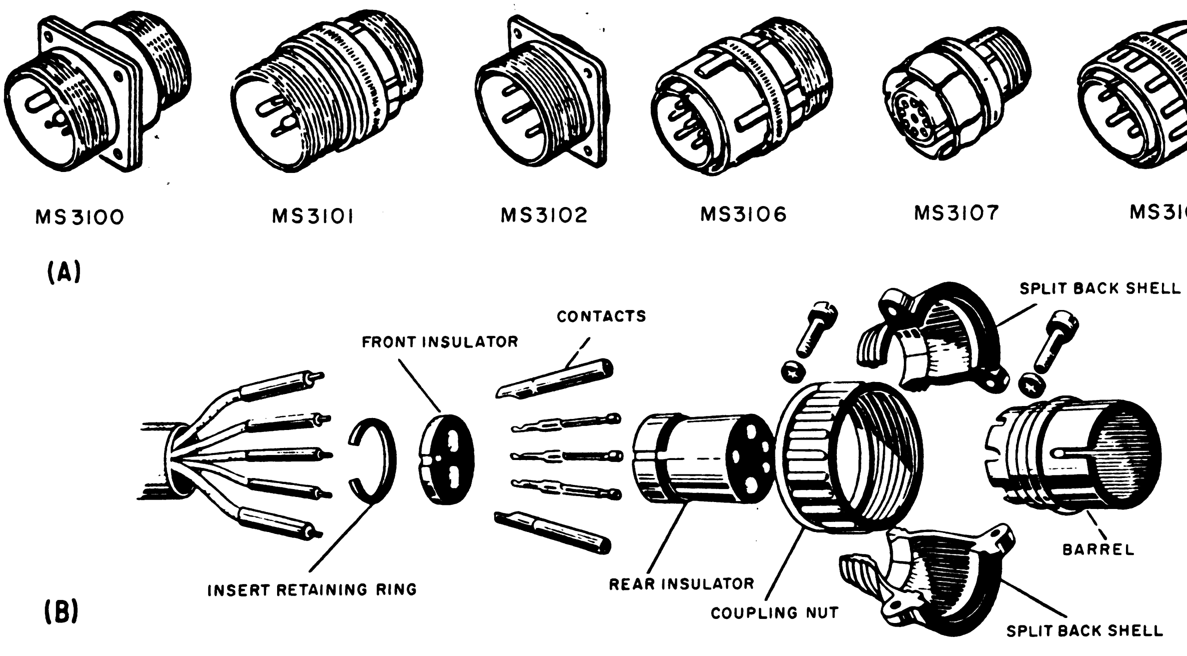

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Figure 13-10.—(A) Connector shells; (B) exploded view of a connector.

dielectric characteristics, it reduces the possibility of arc-over between pins at the back of electric connectors.

The sealant is provided in kit form through the normal supply channels. Sealing (or potting, as it is called) is not required on environment-proof E connectors or connectors located in areas where the temperature exceeds 200° F. The sealing compound deteriorates after long exposure to ambient temperature above 200° F.

The detailed instructions for performing sealing operations may be obtained from the current Electronic Material Change covering this subject. A summary of the procedures involved in sealing a connector is as follows:

1. Prepare a used connector by removing existing sealants and by cleaning. The cleaning solvent used must clean thoroughly, evaporate quickly, and leave no residue. Remove all sleeving from the wires. Resolder loose or poorly soldered connections and add a length of wire approximately 9 inches long to each unused pin. Remove any excess rosin from around the pins and the insert; a stiff bristle brush is helpful in doing this. Now, repeat the cleaning, and then separate the wires evenly.

2. Thoroughly mix the accelerator and base compound (fig. 13-11). The ratio of the amount of accelerator to the amount of base compound is critical; therefore, the entire quantity of accelerator furnished must be added to the base compound.

3. Place the plugs or receptacles on a table, arranging them so that gravity will draw the sealer to the bottom of the plug. Box receptacles or plugs without back shells must be fitted with a mold made of masking tape or cellophane tape or equivalent. (See (A) of fig. 13-12.) This will retain the sealant during the curing process. If the back shell is used, apply a slight amount of oil to the inner surfaces to prevent the compound from adhering to it.

4. The compound is applied by a spatula, putty knife, or paddle. It should be packed around the base of the pins. The part being potted should be completely filled or at least to a point to cover three-eighths inch of insulated wire. The compound is now allowed to cure; temperature will affect the curing time. The normal curing time is approximately 24 hours.

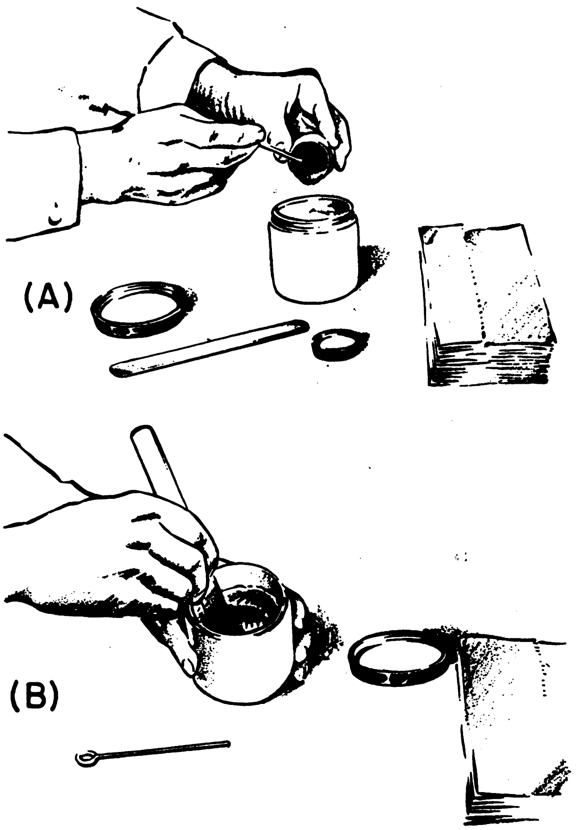

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Figure 13-11.–Combining accelerator with base compound.

If it is desired that the entire connector assembly (plug and receptacle) be sealed against fluid entering or collecting between the two parts, it is necessary that a rubber O-ring be fitted over the barrel of the plug. This will provide a seal when the two parts are engaged securely. If properly installed, this seal will prevent moist air from entering due to variations in temperature, altitude, or barometric pressure on the ground. Rubber packing O-rings are available for this purpose through normal supply channels. Due to the aging of these rings in service, it is necessary to examine them each time the connector is disassembled. If deteriorated, they must be replaced.

The purpose of soldering a short length of wire to each spare pin is to provide for two

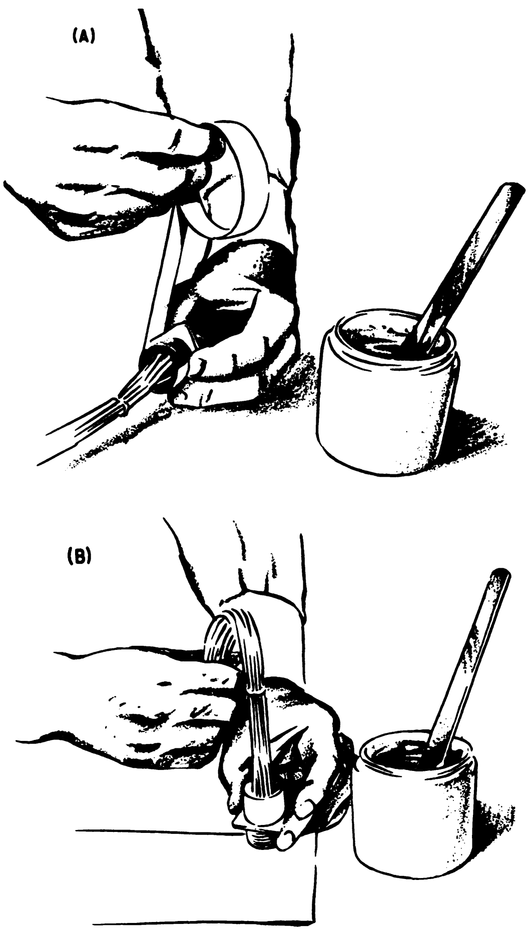

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Figure 13-12.—(A) Making mold from masking tape; (B) finished potted plug.

eventualities: to allow for growth requiring additional circuits to be included in the connector, and to reduce the need of repairing a single wire which may have failed with the connectors by making a splice to one of the spare wires.

CONDUCTORS AND TERMINALS

Although modern technical literature has been emphasizing the use of printed circuits and microelectronic components in contemporary electronic equipment, conductors are still important as a signal- or current-carrying device. (For the purpose of this discussion the term conductor will refer to both wire and cable.) As a significant part of operating equipment, conductors deserve appropriate attention.

Wire

For wire replacement work, the Maintenance Instructions Manual for the particular aircraft or equipment should first be consulted since it normally lists the wire used. When this information cannot be obtained from the manual, the repairman must select the correct conductor needed for the job. The three major factors involved in this selection in descending order of importance, are size, insulation, and the characteristics required to satisfy specific environments in which the wire must function.

CONDUCTOR SIZE.—For d-c applications, the allowable voltage drop and current-carrying capacity govern the choice of size. At radiofrequencies, the skin effect and inductance may become a controlling factor, although generally (except in inductors or RF transformers) these parameters need not be considered. Wire size is therefore basically a function of the current or the allowable resistance, except when this results in a very small conductor size.

Small conductors are difficult to handle and are subject to breakage in soldering or due to vibration. Experience has shown that these difficulties may be avoided by using No. 22 or No. 24 AWG for general circuit wiring and at least No. 20 AWG for parallel connected tube filaments. Solid wire should be used only for short jumper connections not exceeding 3 inches in length, unless the parts being connected are solidly mounted and not subject to vibration. Clamps or "dress lugs" are recommended for long leads. In other words, the use of stranded copper wire whenever possible is strongly recommended, although under extreme conditions of vibration or where high flexibility is required, oxygen-free copper is sometimes specified. Copperclad steel is another possibility for applications requiring greater strength and rigidity.

INSULATION.—A wide variety of insulating material is available, which makes its specification particularly important. Since each insulation has its peculiar characteristics, no single type is therefore always suitable for general usage. The major insulation requirements include good dielectric strength, high insulation resistance (internal and surface), wide temperature range (with high softening and low brittle points), flexibility, color stability, and resistance to abrasion, crushing, moisture, fungus, burning, radiation, oil, and acids.

Insulation requirements for electronic, as opposed to power, applications are somewhat more exacting due to the higher frequencies and impedances and often higher voltages involved. Insulation resistance and dielectric strength are the prime considerations, although for RF application the figure of merit (capacity to Q ratio) becomes important.

Some of the insulations used for general hookup wire include lacquered cotton, high temperature rubber, butadiene styrene copolymers, Celanese, Fiberglas, nylon, vinyl, polyvinyl-chloride, cellulose acetate, polystyrene, polyethylene, Teflon, and various silicon-treated materials. An insulation wall thickness of not less than 0.013 inch is recommended for all wiring within the confines of an enclosure or where mechanical protection is provided. Where wiring is exposed or subject to wear or abrasion, heavier insulation is required.

ENVIRONMENTS.–Environmental factors such as temperature, humidity, altitude, vibration, radiation, fungus, contaminants, and corrosive elements must be taken into consideration. These requirements are included as a part of the specification for the equipment where the wire is to be used.

Terminals

Since most aircraft wires are stranded, it is necessary to use terminal lugs to hold the strands together and facilitate fastening the wires to terminal studs. The terminals used in electrical wiring are either of the soldered or crimped type. Terminals used in repair work must be of the size and type specified on the electrical wiring diagram for the particular models. Soldered and crimped type terminals may be used interchangeably, but both must have the same amperage capacity and the same size hole in the lug.

The increased use of crimp-on terminals is based to a large degree upon the limitations of soldered terminals. The quality of soldered connections depends mainly upon the operator's skill. Such factors as temperature, flux, cleanliness, oxides, and insulation damage due to heat also contribute to defective connections when they are not precisely controlled.

The crimp-on solderless terminals require relatively little operator skill. Another advantage is that the use of a crimping tool eliminates the necessity of supplying power to a soldering iron. This allows terminals to be applied in an aircraft with a minimum of time and effort. The connections are made more rapidly, are cleaner, and are more uniform. Due to the pressures exerted and the materials used, the crimped connection or splice, properly made, has an electrical resistance that is less than that of an equivalent length of wire.

The basic types of terminals are shown in figure 13-13. Part (A) shows the straight type, (B) the right angle type, (C) the flag type, and (D) the splice type. There are also variations of these types, such as the use of a slot instead of a terminal hole, three- and four-way splice type connectors, and others.

Since both copper and aluminum wiring is used in present-day aircraft, both copper and aluminum terminals are necessary. Various size terminal or stud holes will be found for each of the different wire sizes. A further refinement of the solderless terminals is the insulated type; the barrel of the terminal (fig. 13-13) is enclosed in a insulation material. The insulation is compressed along with the terminal barrel when crimping, but is not

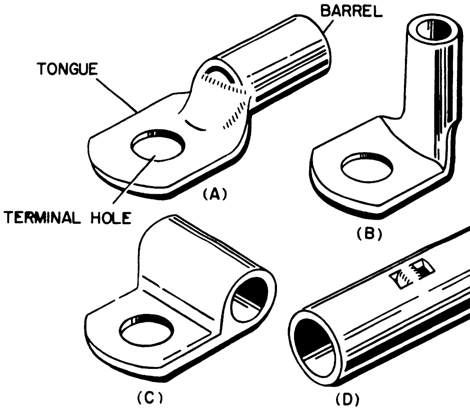

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Figure 13-13.–Types of solderless terminals.

damaged in the process. This eliminates the necessity of taping or tying an insulating sleeve over the joint.

Cable Splicing

A cable splice, other than one made with the crimp-on splice or connector, is employed as an emergency measure only. Solder may or may not be used, as the condition warrants, but in any case the splice should give a good electrical and mechanical joint without solder. The splice should be taped to give insulation equivalent to the rest of the cable. A permanent repair must be made as soon as possible.

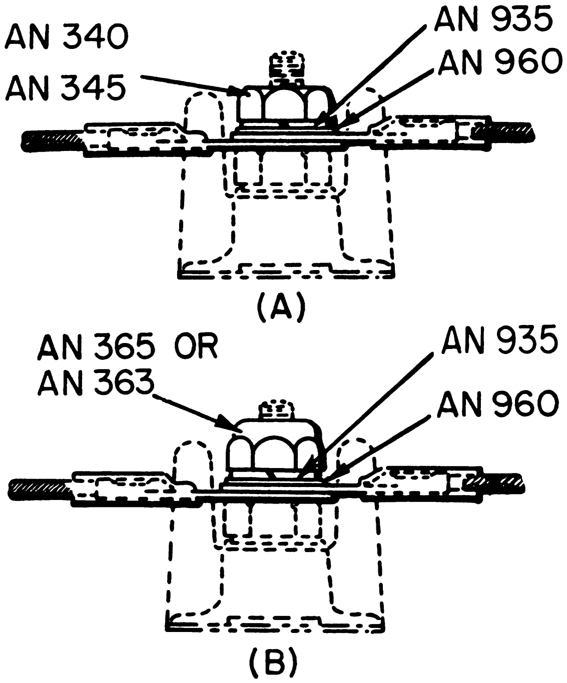
Consult section XII of Engineering Handbook Series for Aircraft Repair, Aircraft Structural Hardware (AN 01-1A-8), and/or Installation Practices for Aircraft Electrical and Electronic Wiring, NavWeps 01-1A-505, for detailed information dealing with attaching cable terminals, forming terminals for emergency use, and repairing damaged or broken cables.

Terminal Blocks and Junction Boxes

Terminal blocks are made from an insulating material which supports and insulates a series of terminals from each other as well as from ground. They provide a means of installing terminals within junction boxes and distribution panels.

Two methods of attaching cable terminals to terminal blocks are illustrated in figure 13-14. In (A) of the figure a standard non-locking nut is used. In this method of installation, the use of a lockwasher is necessary. The preferred method is shown in (B) of the figure. An anchor nut, or self-locking nut, is used and the lockwasher is retained for additional security. The use of anchor nuts is especially desirable in areas of high vibration. In both installations, it is required that a flat washer be employed, as shown in the drawing.

Junction boxes are installed to accommodate electrical terminals or other equipment, such as relays and transformers. Individual junction boxes are named according to their function, location, or equipment with which they are associated. Junction boxes are usually provided with a drain hole (except boxes labeled "vapor-tight") located at the lowest point so that water, oil, condensate, or other liquids will not be trapped.



AE.67

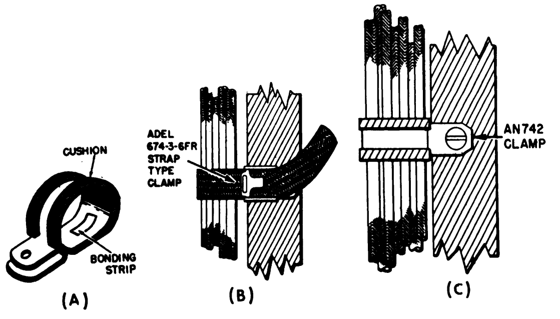
Figure 13-14.—Installation of cable terminals on terminal block.

Insulating Sleeving

Insulating sleeving (commonly called "spaghetti") is used in electronic maintenance operations in many aviation activities. Among the operations involving use of the sleeving are the fabrication of cable connectors, connection to relays and terminal strips, crimped or soldered terminal lugs or splices, tie points on terminal strips or terminal boards, etc.

Support Clamps

Clamps are used to provide support for open wiring, and to serve instead of (or in addition to) lacing on open wiring. They are usually supplied with a rubber cushion. When used with shielded conduit, the clamps are of the bonded type (fig. 13-15(A)); that is, provision is made



AE.69

Figure 13-15.–Cable clamps.

for electrical contact between the clamp and conduit. Unbonded clips are used for the support of open wiring.

Long runs of cable between panels are supported either by a strap type clamp, shown in (B) of figure 13-15, or by a clamp of the type shown in (C) of the same figure. The preferred method of supporting cables for all types of runs is with the type shown in (C). When the strap type clamps are used, precautions must be exercised to insure that they will hold the cables firmly away from lines, surface control cables, pulleys, and all movable parts of the aircraft; these clamps should be used only as an emergency measure.

When cables pass through lightening holes, the installation should conform to the examples shown in figure 13-16. The cable should be routed clear of the edges of the lightening hole, to avoid any possibility of chafing of the insulation.

Lacing and Tying

Wire groups and bundles are laced or tied to provide ease of installation, maintenance, and inspection. The purpose of lacing or tying is to keep all cables neatly secured in groups and thus avoid possible damage from chafing against equipment or interference with equipment operation.

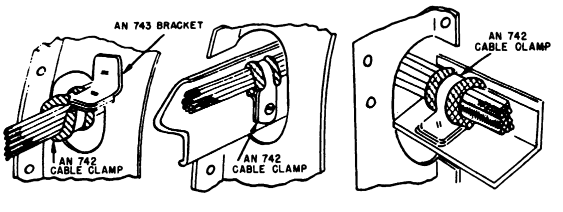


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Figure 13-16.–Routing cables through lightening holes.

TYING is the securing together of a group or bundle of wires by means of individual pieces of cord tied around the group or bundle at regular intervals. LACING is the securing together of a group or bundle of wires inside enclosures by means of a continuous piece of cord forming loops at regular intervals around the group or bundle.

A wire group is two or more wires tied or laced together to give identity to an individual system. A wire bundle is two or more wires or groups tied or laced together to facilitate maintenance.

Cotton, nylon, or Fiberglas cord is used for tying or lacing. The cotton cord must be waxed to make it moisture and fungus resisting. Nylon and Fiberglas cords are in themselves moisture and fungus resisting and are not usually waxed. Pressure sensitive vinyl electrical tape is used only where the use of tape instead of cord is specifically permitted.

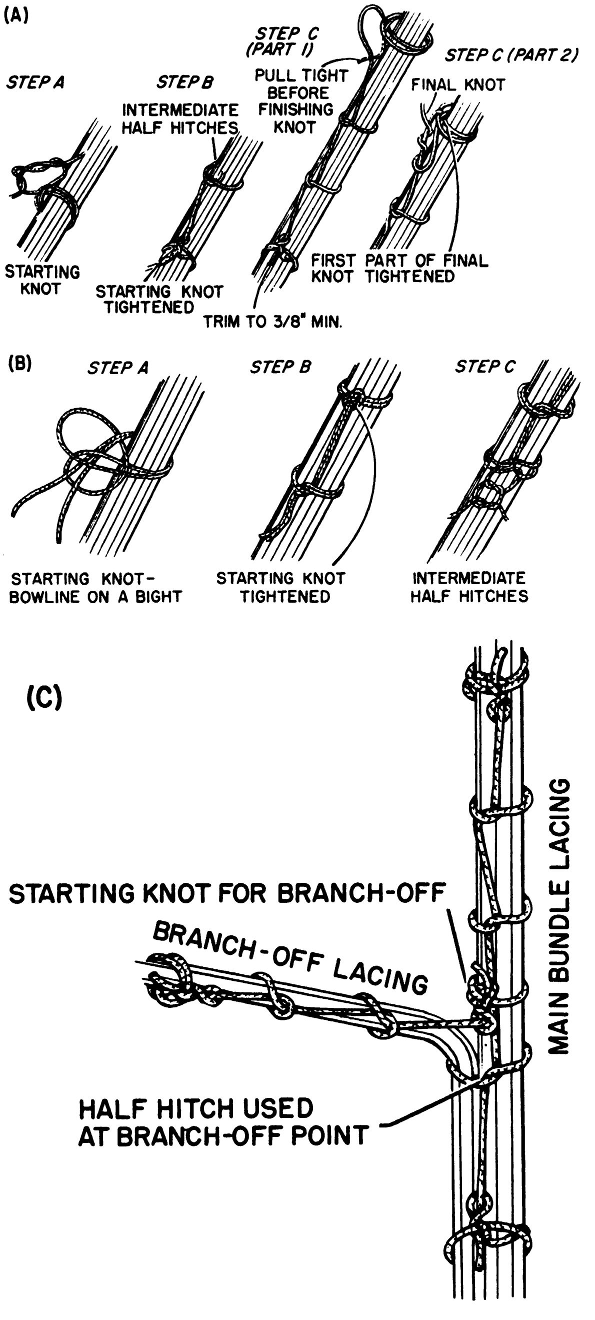
When lacing or tying (fig. 13-17 and 13-18), observe the following precautions:

1. Lace or tie bundles tight enough to prevent slipping, but not so tight that the cord cuts into or deforms the insulation.

NOTE: Coaxial cables have been damaged by the use of lacing materials or by methods of lacing or tying wire bundles which cause a concentrated force on the cable insulation. Elastic lacing materials, small diameter lacing cord, and excessive tightening deform the interconductor insulation and result in short circuits or impedance changes. Avionics Bulletin No. 8 of May 1963 directs the use of the flat nylon braided waxed lacing tape (FSN 4020-730-2622-L980) for lacing or tying any wire bundles which include coaxial cables.

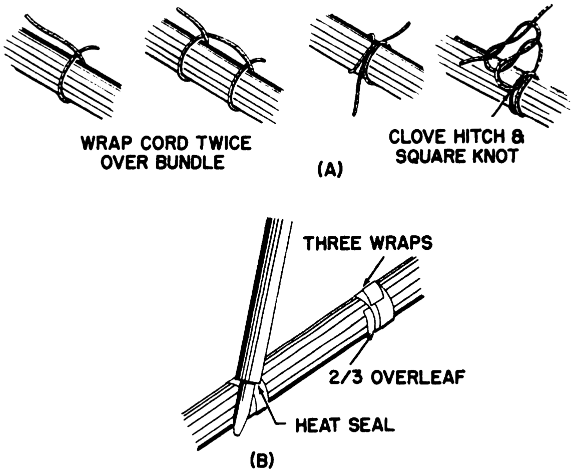
2. Do not place ties on that part of a wire group or bundle that is located inside a conduit.

3. Lace wire groups or bundles only when they are inside enclosures, such as junction boxes. Use double cord on groups or bundles larger than 1 inch in diameter. Use single or double cord for groups or bundles 1 inch or less in diameter.


(A)
STEP A
STEP B
STEP C (PART I)
PULL TIGHT BEFORE FINISHING KNOT
STEP C (PART 2)
FINAL KNOT
INTERMEDIATE HALF HITCHES
STARTING KNOT
STARTING KNOT TIGHTENED
FIRST PART OF FINAL KNOT TIGHTENED
TRIM TO 3/8" MIN.
(B)
STEP A
STEP B
STEP C
STARTING KNOT-BOWLINE ON A BIGHT
STARTING KNOT TIGHTENED
INTERMEDIATE HALF HITCHES
(C)
STARTING KNOT FOR BRANCH-OFF
BRANCH-OFF LACING
MAIN BUNDLE LACING
HALF HITCH USED AT BRANCH-OFF POINT

AT.270

Figure 13-17.—Lacing wire groups or bundles.



AT.271

Figure 13-18.—Tying wire groups or bundles.

In some instances groups or bundles may be secured with tape. (See fig. 13-18(B).) The following method should be employed:

1. Wrap tape around wire group or bundle three times, with a two-thirds overlap for each turn.
2. Heat-seal the loose tape end with the side of a soldering iron heating element.

Do not use tape for securing wire groups or bundles which may require frequent maintenance.

An excellent source of additional information in connection with power distribution is NavWeps 01-1A-505, Installation Practices for Aircraft Electric and Electronic Wiring. This manual presents the recommended practices and techniques to be used for installing, repairing, and maintaining aircraft electric wiring. It includes information under the following headings: Wire and cable preparation; general-purpose connectors; RF connectors and cabling; solderless terminations and splicings; thermocouple wire solderings and installation; bonding and grounding; bus bar preparation; conduit fabrication; installation of bus bars, conduit, junction boxes, protective devices, and terminal strips; electrical wiring installation; lacing and tying; safety wiring; and emergency repairs.

BONDING

A bond is any fixed union existing between two metallic objects that results in electrical conductivity between them. Such a union results from either physical contact between conductive surfaces of the objects or from the addition of a firm electrical connection between them. Aircraft electrical bonding is the process of obtaining the necessary electrical conductivity between the component metallic parts of the aircraft. An isolated conducting part of an object is one that is physically separated by intervening insulation from the aircraft structure and from other conductors which are bonded to the structure.

A bonding connector provides the necessary electrical conductivity between metallic parts in an aircraft not in sufficient electrical contact. Examples of bonding connectors are bonding jumpers and bonding clamps. (See fig. 13-19.)

An aircraft can become highly charged with static electricity while in flight. If the aircraft is improperly bonded, all metal parts will not have the same amount of charge. A difference of potential will then exist between various metal surfaces. The neutralization of the charges flowing in paths of variable resistance, due to such causes as intermittent contact from vibration or the movement of the control surface, will produce electrical disturbances (noise) in the radio receiver. If the resistance between isolated metal surfaces is great enough, charges can accumulate until the potential difference becomes sufficiently high to cause a spark. In addition to creating radio interference, this also constitutes a fire hazard. In the case of lightning striking the aircraft, a good conducting path is necessary for the heavy current in order to minimize severe arcs and sparks which would damage the aircraft and possibly injure its occupants.

The aircraft structure is also the ground for the radio. For the radio to function properly, a proper balance must be maintained between the aircraft structure and antenna. This means the surface area of the ground must be constant. Control surfaces, for example, may at times become partially insulated from the remaining structure due to a film of lubricant on the hinges. This would affect radio operation if the condition were not taken care of by bonding.

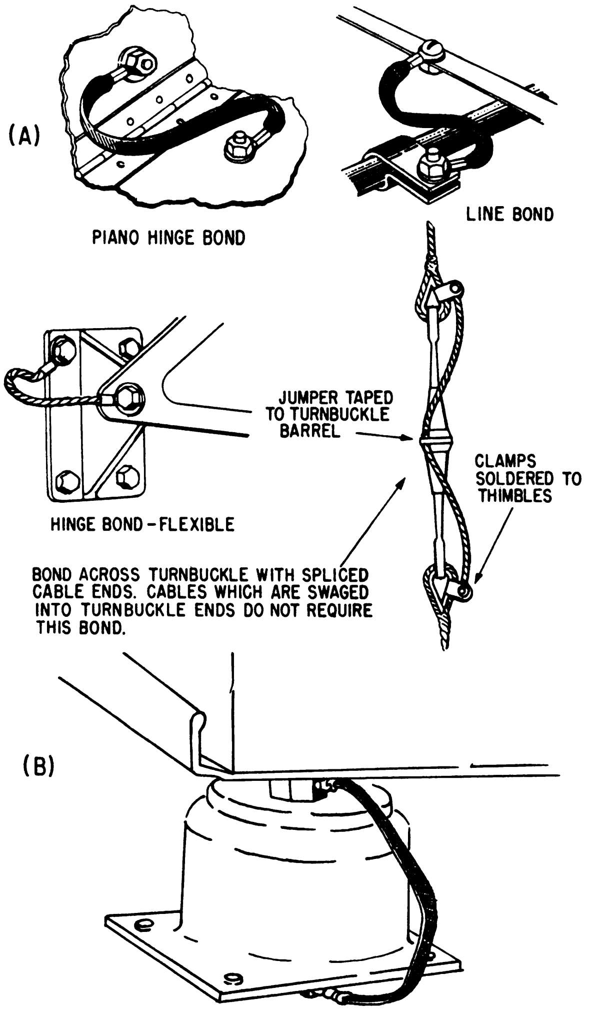

(A)
PIANO HINGE BOND
LINE BOND
HINGE BOND - FLEXIBLE
JUMPER TAPED TO TURNBUCKLE BARREL
CLAMPS SOLDERED TO THIMBLES
BOND ACROSS TURNBUCKLE WITH SPLICED CABLE ENDS. CABLES WHICH ARE SWAGED INTO TURNBUCKLE ENDS DO NOT REQUIRE THIS BOND.
(B)
AT.272

Figure 13-19.–Bonding methods.

Bonding also provides the necessary low-resistance return path for single-wire electrical systems. This low-resistance return path also aids the effectiveness of the shielding, and provides a means of bringing the entire aircraft to the earth potential when it is grounded.

The reason for bonding may be summed up as follows:

1. To minimize radio and radar interferences by equalizing static charges that accumulate.

2. To eliminate a fire hazard by preventing static charges from accumulating between two isolated members and creating a spark.

3. To minimize lightning damage to the aircraft and its occupants.

4. To provide the proper ground for proper functioning of the aircraft radio.

5. To provide a low-resistance return path for single-wire electrical systems.

6. To aid in the effectiveness of the shielding.

7. To provide a means of bringing the entire aircraft to the earth's potential and keeping it that way while it is grounded to the earth.

Bonding connection should be installed so that vibration, expansion or contraction, or relative movement incident to normal service use will not break the bonding connections or loosen them to such an extent that the resistance will vary during the movement. The bonding of most concern will be the bonding jumpers that are placed across shock mounts, used to support electronic equipment.

Since a primary objective for bonding is to provide an electrical path of low d-c resistance and low RF impedance, it is important that the jumper be a good conductor of ample size for the current-carrying capacity, have low resistance, and be as short as possible. Insofar as practical, parts should be bonded directly to the basic aircraft structure rather than through other bonded parts. Bonding jumpers should be installed in a manner so as not to interfere in any way with the operation of movable components of the aircraft.

Contact of dissimilar metals in the presence of an electrolyte, such as salt water, produces an electric action (battery action) which causes a pitting in one of the metals. The intensity of this electric action varies with the kinds of metals. Bonding frequently necessitates the direct contact of dissimilar metals. In such cases the metals used are of the kind that will produce a minimum of corrosion. The connections are also made so that if corrosion does occur, it will be in replaceable elements, such as jumpers, washers, or separators, rather than in the bonded or bonding members. Thus, washers made of the same material as the structural member should be used against the structural member, and washers of the same material as the bonded member should be in contact with that item.

Self-tapping screws should not be used for bonding purposes nor should jumpers be compression-fastened through plywood or other nonmetallic material. When performing a bonding operation, the contact surfaces should be cleaned of insulating finishes or surface films before assembly, and then the completed assembly refinished with a suitable protective finish.

Consult Installation Practices for Aircraft Electric and Electronic Wiring, NavWeps 01-1A-505, for more detailed information dealing with bonding.

SHOCK MOUNTS

Electronic equipment is sensitive to mechanical shock and vibration; therefore, units of electronic equipment are normally shock mounted to provide some protection against inflight vibration and against launching and landing shock. The specific type shock mount is prescribed in the Maintenance Instructions Manual for the specific aircraft, and substitution should not be made.

Periodic inspection of shock mounts is required, and defective mounts should be replaced with the prescribed type. In the inspection, the main factors are chemical deterioration of the shock absorbing material, stiffness and resiliency of the material, and overall rigidity of the mount. If the mount is too stiff or too rigid, it may not provide adequate protection against the shock of launching and landing; if it is not stiff or rigid enough, it may permit prolonged vibration following an initial shock. When determining the limits of rigidity and resiliency, consideration must be given to the weight of the mounted unit as well as the amounts of positive and negative acceleration to which it is subjected.

Shock absorbing materials commonly used in shock mounts are usually electrical insulators. For the sake of safety, it is required that each electronic unit mounted in this manner must be electrically bonded to a structural member of the aircraft. (See fig. 13-19 (B).) The bonding strap should also be included in the inspection of the shock mounts, and defective or ineffective bonds should be replaced or reinstalled.

SAFETY WIRING

Before an installed unit can be considered secured for flight, it must be safety wired properly. Two common methods—the single twist and the double twist—are used. Figure 13-20 illustrates typical examples of each method.

Specific items which normally require safety wiring include cable connectors, drilled-head bolts or screws and nuts, thumbscrews and wingnuts on mounting racks, switchguards which are required to retain a switch in a specified position but which could be placed inadvertently into the wrong position, and most threaded items which do not use cotter pins or self-locking nuts.

The double twist method is the most common method of safety wiring, and should essentially be as shown in figure 13-20(A). The twisting may be accomplished by hand with the exception of the final few twists which should be done with pliers in order to apply tension and secure the ends of the wire properly. The safety wire should always be installed and twisted so that the loop around the head stays down and does not tend to come up over the bolthead, causing a slack loop. Extreme care must be used when twisting the wires together to insure that they are tight but not overstressed to the point where breakage will occur under slightly greater than normal load or vibration.

The single twist method of safety wiring may be used on small screws in a closely spaced area, if the screws form a closed geometrical pattern. Figure 13-20(B) illustrates a typical application where the single wire method may be used.

Finished ends of safety wire should be bent back or under to prevent injury to personnel (fig. 13-20(C)). The safety wire should be as short as practicable, and must be installed in such a manner that the pull on the wire is in the direction which tightens the movable item (fig. 13-20(D)).

When safety wiring widely spaced bolts by the double twist method, a group of three should be the maximum number in a series. When safety wiring closely spaced bolts, the number that can be safety wired by a 24-inch length of wire should be the maximum number in a series.

Torqued parts being safety wired should be torqued to recommended values and holes alined before attempting to proceed with the safetying operation. Never overtorque or loosen a torqued nut to aline safety wire holes.

Whenever a safety wire is broken for maintenance or other cause, it must be replaced using the proper procedure. Any time a required safety wire is not replaced, an in-flight failure may result.

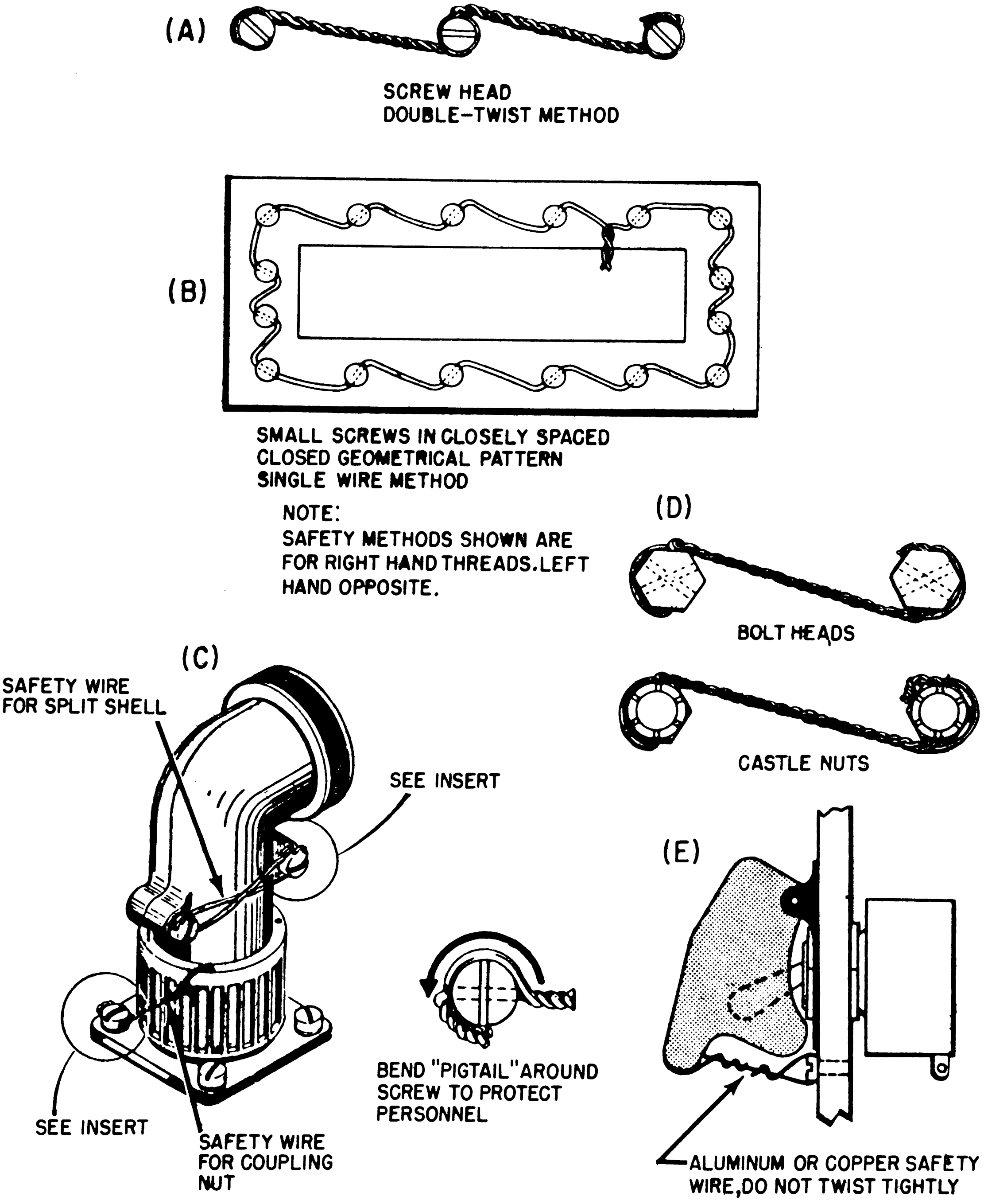


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Figure 13-20.—Safety wiring methods.

CHAPTER 14

ELECTRONIC MAINTENANCE, PART II

ENVIRONMENTAL PROBLEMS

Although the need for reliability in military avionics equipment has remained relatively constant since the start of World War II, the difficulty of attaining this reliability has increased. The continually increasing complexity of avionics equipment and the subjection of equipment to more and more rigorous environmental conditions are among the chief causes of equipment failure. For these reasons the technician should understand the effects of environmental conditions on the equipments and the design techniques used to minimize these effects.

The environmental factors that should be understood in order to maintain the design characteristics include temperature, humidity, pressure, and abrasive conditions.

TEMPERATURE

Extensive research has been conducted to develop external component parts that are better able to withstand operation under extreme temperatures. Extremely low temperatures cause brittleness in metal and loss of flexibility of rubber, insulation, and similar materials. Extremely high temperatures may cause deformity and deterioration of these items. Most internal component parts are not able to withstand these extreme temperatures.

Because equipment is normally installed in confined spaces aboard aircraft, the generated heat causes the temperature to rise; therefore, many units have fans installed to increase the air circulation, thus reducing the temperature within the unit. Most of the new models of aircraft utilize the electronic equipment compartment concept, and use blast air from outside the aircraft or from the aircraft's air-conditioning system for cooling.

HUMIDITY

Humidity, a measure of water content in the air, is a possible cause of avionic equipment or component failure. High humidity (that is, a high water content in the air) provides a possible environment for corrosion and fungus growth. A high moisture content in the air may cause short circuiting between points of high potential.

In certain cases the removal of heat from equipment requires the use of external air. If this external air has a high moisture content, the cooling may be accomplished by one of two ways. First, the high humidity air may be directed through an air jacket which surrounds the equipment. In this case the heat is removed without allowing the humid air to come in contact with the internal equipment components. Second, when the internal equipment components require direct air for heat removal, the direct air is passed through silica-gel crystals, removing the moisture from the air. It should be apparent that the second method is less troublesome because the first case does cause corrosion within the air jacket.

PRESSURIZATION

When high-voltage avionics equipment is operated at high altitudes without being pressurized, there may be the problem of arc-over. This is caused by the reduced dielectric strength of the air as it becomes less dense. To reduce the possibility of arc-over, the equipment is pressurized.

When troubles occur in the system, a check for evidence of arc-over should be made. This may be indicated by blown fuses, charred insulation, and pitting of metal close to high voltages.

ABRASIVE CONDITIONS

Sand, dust, and other substances which are abrasive in nature affect many components. Generally these components are parts that are not sealed off from the atmospheric conditions. In some cases the abrasive material is formed even though the unit is sealed. Examples are generators, motors, and dynamotors which use brushes. Also the protective coating may be removed from a part by the movement of the abrasive material in the air that is used for cooling. This may allow the unprotected metal to corrode.

Modern aircraft configurations employ the use of air-conditioning systems for the purpose of cooling the avionics equipments. The external air is used to cool the heat exchanger while the internal air used to remove heat from the equipment may be pressurized. The use of the pressurized air for equipment heat removal minimizes the undesired environmental effects of temperature, humidity, arc-over, and abrasive conditions. An example of a single equipment air-conditioning system is shown in figure 16-18 of chapter 16. Multiple equipment packages utilize the air-conditioning system of the aircraft.

CORROSION CONTROL

In modern aircraft, the need for corrosion control has become a major concern in the availability and maintenance of our striking forces. This is because corrosion is something that destroys equipment and is active 24 hours a day. It is of the utmost importance that its nature be understood in order to combat corrosion.

Most of the useful metals used today have been refined from natural ores found in the earth's surface. These metals are extracted from the ore and are used in various combinations to form alloys with distinct properties. Some of these properties are light weight, strength, and resistance to extreme temperatures. These refined metals have a tendency to return to their natural state, but proper corrosion control will prevent this action taking place.

With the strength demands being made of metals, corrosion control becomes more important because corrosion weakens the metals, thereby causing structural failure. This type failure will cause aircraft safety to decrease and cost of repairs to increase.

CHEMICAL CORROSION

Most surface corrosion is chemical in nature and is generally caused by salts, acids, or gases coming in contact with the metallic surfaces of the aircraft or equipment.

Aircraft and their associated equipment which are based aboard ship are particularly vulnerable to salt spray and gases which originate on board a ship. Shore-based aircraft are also exposed to contamination, but to a somewhat lesser degree. Although salt spray and gases in the atmosphere cause rapid chemical corrosion, it should be understood that some corrosion will take place under the most ideal situations.

Chemical corrosion is a chemical process which is esentially the reverse of the process of extracting the metals from their ores. For the most part, metals occur naturally as metallic oxides. After refining, regardless of whether or not alloyed, base metals generally possess a tendency to return to their natural state. However, this is not sufficient in itself to initiate and promote this reversion. There must also exist a corrosive environment in which the significant element is oxygen. Corrosion, then, is the process of oxidation.

ELECTROCHEMICAL CORROSION

While chemical corrosion is generally readily apparent, electrochemical corrosion is insidious in its destruction. Electrochemical corrosion includes galvanic or dissimilar metals corrosion. This type of corrosion is caused by an exchange of electrons between two metallic areas of different activity (potential) by way of an electrolyte. Three conditions must be present in order for electrochemical corrosion to take place. The first condition is that two or more areas of metal are needed to act as electrodes. The second condition is the requirement of the presence of an electromotive force. The last requirement is the presence of an electrolyte to complete the formation of a cell.

It is not necessary to know all the theories concerning electrochemical corrosion, but a brief understanding of the deterioration of metals will be beneficial in combating this type of corrosion.

An ordinary flashlight cell serves as a good subject to explain electrochemical corrosion. (See fig. 14-1.) The outside container is made of zinc and serves as the anode which is corroded as the cell is operated. The cathode of the chemical cell is the carbon electrode in the center of the cell. The moist ammonium and zinc chloride paste within the zinc container is the electrolyte which electrically connects the carbon electrode with the zinc anode.

If a conductor is connected externally to the electrodes of a cell, electrons will flow under the influence of a difference of potential across the electrodes from the zinc (-) through the external circuit to the carbon (+) returning within the electrolyte to the zinc. As the electrons flow, the zinc coating will oxidize. This oxidation is the same as corrosion. For a more detailed explanation of the operation of a cell, refer to Basic Electricity, NavPers 10086-B.

Since the only requirements for a cell are cathode, anode, and electrolyte, it should be apparent that the physical size of a cell is dependent only on the physical size of its components. A cell may be formed where a resistor lead is soldered to a terminal, two sheets of metal are joined, or around a rivet head and the adjacent metal. (See fig. 14-2 (A) and (B).) A cell may even be formed when an electrolyte is present on one piece of metal where two metallic crystals in the same alloy, but of different composition, are in electrical contact with each other. (See fig. 14-2 (C).)

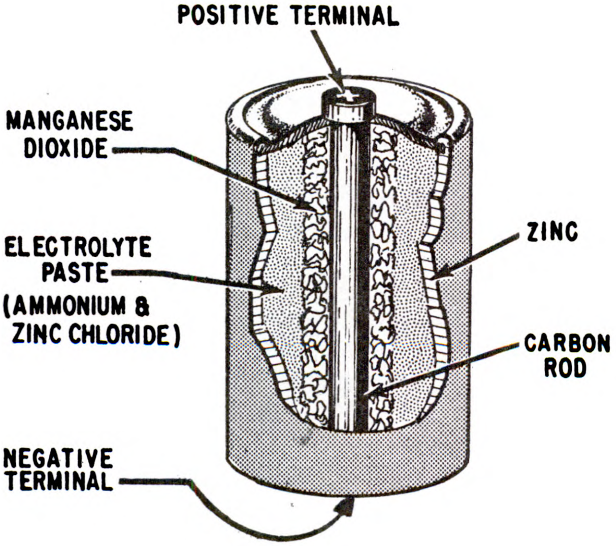

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Figure 14-1.–Dry cell, cross sectional view.

While the formation of one minute cell may be insignificant, it should be understood that a cell will continue to grow as long as the corrosion action is allowed to continue. This cell expansion may take place in a short period of time and become a significant structural safety factor due to the deterioration of the metal.

It should be apparent that the presence of an electrolyte allows corrosion to take place. The more efficient the electrolyte and the greater the potential difference between anode and cathode, the higher the corrosion rate (growth) will be. It should be noted that the anode and cathode are always present and cannot be removed; therefore, the solution to the problem of corrosion is to remove the electrolyte. When the electrolyte is removed, a cell no longer exists and corrosion is held to the minimum.

Both types of corrosion normally depend on moisture to form an electrolyte. Even moisture in the air is often sufficient to start the corrosion action. All attacks of corrosion start on the surface of the metal where it is exposed to the corrosive environment; and if allowed to progress, it will work its way into the core of the material. Since corrosion never originates in the core, there is always some form of evidence of corrosion on the surface.

CORROSION PREVENTION

Now that it is understood that the "villain" of corrosion is the electrolyte, the solution to corrosion prevention is to keep any electrolyte from coming into contact with the electrodes. This is accomplished by keeping a protective coating on the metallic surfaces.

Much has been done to improve the corrosion resistance of naval aircraft. This is in the area of improvement in materials, surface treatments, insulation, and protective finishes.

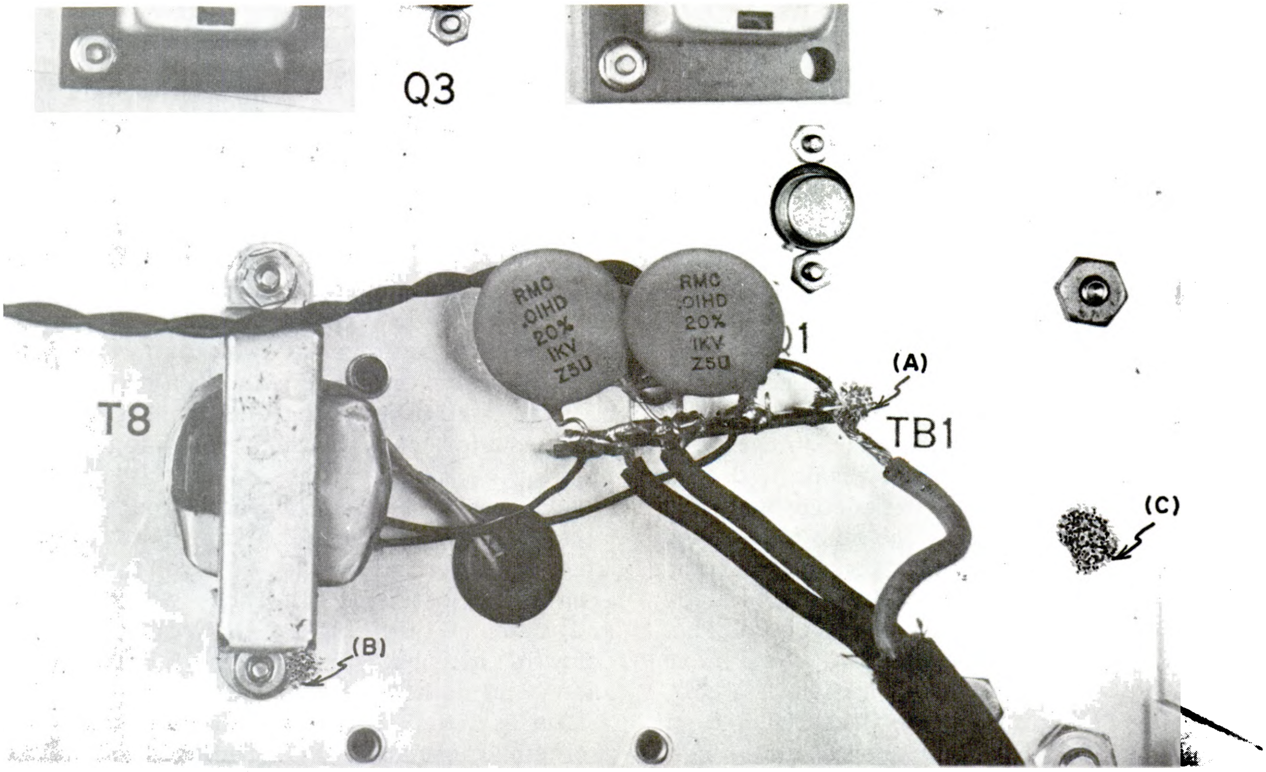

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Figure 14-2.–Electrochemical corrosion.

All of these have been aimed at reducing maintenance effort as well as improving reliability. In spite of these improvements, corrosion and its control are very real problems that require a continuous preventive maintenance program.

Corrosion preventive maintenance includes the following special functions:

1. An adequate cleaning program.
2. Thorough periodic lubrication.
3. Detailed inspection for corrosion and failure of protective systems.
4. Prompt treatment of corrosion and touchup of damaged protective coating.

Inspection

Inspection for corrosion is a continuing problem and should be handled on a day-to-day basis. Overemphasizing a particular corrosion problem when it is discovered, and then forgetting about corrosion until the next crisis, is an unsafe, costly, and troublesome practice.

Most periodic maintenance requirement information has been placed on Maintenance Requirements Cards which are complete enough to cover all equipments in the aircraft. No equipment of the aircraft should go unchecked. Through experience, it will be learned that most equipments have trouble areas where corrosion will occur. Equipments in helicopters are particularly susceptible to corrosion due to the tactics in which the helicopters participate.

Protective Measures

An effective protection from corrosion requires the earliest possible repair of damaged protective coatings, including the removal of corrosion products and the restoration of corroded surfaces. This involves the maximum use of supplementary protective agents during any waiting periods or until such time as more positive protection can be restored. It must be a continuous program and recognized as a specific responsibility.

Periods of neglect or touchup maintenance, which may be necessaay under operating conditions, should be followed by a period of concentrated effort to correct any deficiencies which have started. A successful preventive maintenance program will tend to reduce the effects of severe service environments and the susceptibility of most aircraft and equipment to damage by these environments.

ANTICORROSION MATERIALS. — During manufacture, electronic equipments are usually sprayed with a protective coating that seals out moisture, thus preventing corrosion and fungus growth. In repair of these equipments, it is sometimes necessary to remove the protective coating by scraping or by the use of a solvent cleaner.

After making circuit repairs, the protective coating should be replaced. Rosin fluxes form coatings on solder connections that prevent oxidation during and after the soldering process, thus providing one form of replacement. A good general rule is that materials used should be those covered and controlled by military specifications, preferably those authorized specifically for use on aircraft. Use nonspecification materials only in emergencies, or where specific instructions so direct.

FUNGUS-RESISTANT MATERIALS.–Fungus susceptibility of materials has long been a serious problem, particularly with electronic equipments which may be subjected to extremes of humidity under tropical temperatures. While the fungus itself is objectionable since it generally "fouls" all types of equipment, its most serious effect is the increased possibility of shorting and arcing because of its moisture content.

The fungus problem has been further aggravated in the past decade by the increased use of a large number of organic materials in equipment used by the Navy. These materials vary in nature and size from large sheets of reinforced plastic for structural components to special dielectric substances used in complex electronic gear.

Fungus removal generally follows the same procedures of corrosion removal.

CORROSION REMOVAL

In corrosion control, time is of the essence. Until the electrolyte is removed, the chemical reaction will continue. Although most of the electrolyte is removed, some will remain in inaccessible locations of the chassis or modules making the cleaning process particularly difficult.

When this occurs, the proper procedures and cleaning materials must be used. The remainder of this discussion will be devoted to the techniques and materials used in correcting this problem.

The extent of cleaning, using the following techniques, requires the decision of the Corrosion Control Officer assigned to the organization.

Dry Cleaning

When corrosion or salt crystals are discovered in a piece of equipment, as much of this as possible should be removed by dry methods. This entails breaking the solids from the metallic parts by wiping with a dry cloth or brushing with a stiff bristle brush. Care should be taken not to damage any of the components of the equipment.

Any loose residue should be removed by the use of low pressure dry air.

Although it may appear that all of the contamination has been removed, this generally is not the case. At this point a decision must be made as to the possibility of contamination existing in the inaccessible or undetectable areas of the equipment. If this decision indicates that contamination still remains in the equipment, then further steps must be taken in the form of liquid cleaning.

Fresh Water

Although immersion or flushing of electronic and other equipment in or with water violates previous training, fresh water is one of the agents used to remove salt water and deposits from equipments. After the equipment has been subjected to fresh water, the water must then be removed. This may be accomplished by dry air pressure, by the use of a spray (displacement) fluid, or by a drying oven.

DRY AIR PRESSURE.–If compressed air is not available, any type of compressor that will deliver clean dry air at 80 psi will be adequate to furnish air for spray cleaning and for blowing as much water as possible from the wet equipment before using the water-displacing fluid.

WATER-DISPLACING FLUID.–This fluid is generally available in pressurized aerosol cans or in drums and is called a spray-dry water-displacement composition. A paint spray gun or other spraying equipment for applying bulk water-displacing composition in a fine mist may be used if an aerosol-pressurized water-displacing composition is not available.

The equipment is sprayed with this composition, and then some means of drying such as heat oven, air pressure, or natural evaporation should be employed.

DRYING.–Forced draft ovens with accurate temperature control large enough to accommodate the equipment being cleaned are preferable for final drying of the cleaned equipment. If ovens are not available, a small room equipped with an exhaust fan and heaters can be used. The temperature in the drying facilities should be between 120° and 160° F, depending upon the temperature sensitivity of the equipment being dried. If a heated room is used for drying, its temperature should be at least 30° F above the ambient temperature.

Detergent

In some cases a detergent must be used. The detergent is available in aerosol type containers or in bulk form. Detergent is used because salt crystals have formed on the equipment or an oily deposit is present in the equipment. The detergent will dissolve the salt crystals and will also emulsify and suspend oil deposits in the solution. In either case, fresh water must be used to rinse the contaminated solution from the equipment.

Ultrasonic Tanks

An ultrasonic tank is a container for fresh water or a cleaning agent. The solution is vibrated either by a transducer or by forced air. The agitation helps remove particles from inaccessible areas of the electronic equipments. The frequency of the transducer is in the ultrasonic range (above 15 kilohertz) and accomplishes the cleaning in a much shorter period of time than the forced air. When equipment has been removed from an ultrasonic tank, the previously mentioned procedures for drying should be completed.

SALVAGE PROCEDURES

The following steps comprise the routine procedure for salvaging sea water contaminated electronic equipment:

1. Immediately after removal of the equipment from sea water contamination, the equipment should be flushed thoroughly with fresh water.
2. The equipment should be disassembled to units of a size that permits immersion in an ultrasonic bath and to allow better access of cleaning solutions.
3. Remove contamination with emulsion cleaning composition in the ultrasonic tank.
4. Rinse in an ultrasonic tank of fresh water or rinse with a fresh water spray.
5. Blow the rinse water from the equipment with clean compressed air and follow with an application of water displacing composition.
6. Dry in an oven or by natural evaporation.
7. Check for damage, repair and lubricate as required, then return to service.

Equipment which cannot be dismantled or is too large for cleaning in the ultrasonic tank can often be cleaned by spraying with a cleaning emulsion. Upon completion of the emulsion application, the equipment should be rinsed and dried as previously indicated.

CARE AND SERVICING

The operating quality, stability, and reliability of electronic equipment are strongly affected by the quantity and quality of maintenance. Shiny dials and polished handles may be impressive, but it is the care and upkeep of the equipment behind the front panel that determines the operational capabilities of an electronic system.

The minimum requirements for routine care and servicing are listed in the inspection requirements for aircraft and in the technical manuals for specific equipments. The discussion in this chapter is limited to specific items that present special problems or that require special techniques.

SPECIFICATIONS AND PROCEDURES

Detailed instructions, procedures, and specifications for the care, handling, stowage, and servicing of electronic items of equipment are contained in the Operation and Service Instruction Manual for each equipment and in the Maintenance Instructions Manual for each aircraft in which that item is installed. All such procedures must be followed exactly; the specifications must be closely observed. Some components, however possess certain characteristics which warrant special discussion in this context. It must be noted that many of the considerations listed in the following discussion as applying to specific components are, in fact, general considerations which apply to many other components as well.

SPECIAL COMPONENTS

The purpose of this discussion is to provide the information needed to handle magnetrons and other electron tubes properly and to understand why careful handling is necessary. Most of the information supplied may also be applied to other items of electronic equipage.

Magnetrons

Although magnetrons are usually large and heavy, and appear to be rugged, they are actually extremely delicate items. Many of the individual parts are very delicate, and they must remain in precise alinement if the magnetron is to operate properly. Jars, jolts, and vibrations can cause misalinement and render the magnetron useless. The magnet itself, although made of solid metal, can lose its magnetic strength if improperly stowed or handled, resulting in poor performance of the magnetron.

Manufacturers of magnetrons are required to package them according to very rigid specifications. The containers are designed to give the magnetron mechanical support to prevent crushing damage, resilient support to cushion it against shocks and vibrations, and a safe minimum distance from other magnets or ferromagnetic materials. (Magnets stowed close together or close to steel shelves, bulkheads, or other ferromagnetic objects will gradually lose their magnetic strength.)

A magnetron should be retained in its original container until needed for immediate installation. It should not be removed from its carton to conserve space and weight, but should be stowed in the complete container, regardless of the weight and space factors involved.

When unpacking a magnetron for immediate installation, all parts of the container–the outer and inner casings, the support brackets and braces, the mounting hardware, the plastic covers for receptacles and mechanical connectors, the cushion materials, etc.–should be retained for packing the magnetron removed from service.

Magnetrons which have been removed from service are often returned to the manufacturer or some other activity for analysis. These magnetrons must be treated in the same manner as when new–magnetrons damaged after removal from service cannot be analyzed for the cause of original failure. The container should be plainly marked to indicate that it contains a used tube.

Whenever a used magnetron is reshipped, it must be accompanied by all papers and records pertaining to its performance history, hours of operation, and reason for removal. Such paperwork is valuable in the analysis of the failure, and results in improved reliability of magnetrons.

The ceramic window and insulator are convenient places on which to make notations. Such markings form conduction paths which can cause arc-over; therefore, notations should never be made at these locations. (If notations are deemed necessary, use a tag tied at a convenient and acceptable location, or tacked to the outer container).

Magnetrons themselves are not sensitive to either high or low temperatures. However, to avoid possible damage from freezing, liquid-cooled magnetrons must be thoroughly drained and dried before repacking and stowage. If the coolant does not contain an antifreeze, the magnetron should be flushed with ethylene glycol or alcohol before drying in case some liquid remains trapped in the cooling jacket. These steps should be taken any time a magnetron is repackaged, whether for reshipment or for stowage.

Electron Tubes

Electron tubes are generally considered among the most essential components in electronic equipment. Many types of receiving tubes have an expected useful life of 2,000 hours or more when used within their design limitations. Some types of transmitter tubes have similar life expectancies. However, many of the tubes used in airborne military equipment are not operated within design limitations, and therefore may have somewhat shortened life expectancies. Some of the more important factors which affect the actual useful life of electron tubes are discussed briefly in the following paragraphs.

Receiving tubes used in blocking oscillators, peaking or squaring amplifiers, or similar circuits are violently overdriven. It is reasonable to expect that such treatment may shorten the operating life of such tubes. On the other hand, operating a tube well below its power rating may be expected to lengthen its useful life. Thus it may be seen that the operation of the tube in its particular circuit application helps determine its operating life expectancy.

Filament burnout may be caused by repeated sudden application of full voltage to the filament. Since the initial surge of current through the cold filament is many times the rated operating current, initial heating of the filament is non-uniform. As a result, mechanical stresses due to thermal expansion are set up; these stresses weaken the filament structure and hasten its failure. In equipments where the filament power is switched on and off, these mechanical stresses may reasonably be expected to shorten tube life. In equipments where the filaments are left on and the plate voltages are switched, tubes should last longer.

In circuits where the filaments are frequently switched on and off, the tube elements expand and contract during the process of heating and cooling. The electrodes may soon begin to lean or sag, causing excessive noise loosened or broken elements, or microphonics to develop. While testing a circuit suspected of microphonics, an indication of loose elements or microphonics may be obtained by sharply tapping the tube while in operation, and noting the effects on the output indications. If the tube has no defects, there should be no appreciable change in the output indications.

Mechanical defects and increased gas within the tube may be due to faulty construction or to subsequent physical damage. Some manufacturing defects may not be detectable by standard testing methods until tubes have been in service for some time. Physical damage to a tube is usually the result of accidental abuse. It includes such factors as breakage, bent pins, loosened or detached tube parts due to excessive vibration or shock, leakage in the glass-metal seal, application of excessive voltage, etc.

Tubes with glass envelopes provide visible evidence of open filaments, excessive plate current, gas, or arcing. Metal-encased tubes may be felt to determine whether the filament is operating.

Changes in tube characteristics occur as a natural result of aging. Decreased emission results from deterioration of the cathode surface, formation of cathode interface surface in the tube, or decreased heating effeciency of the filament. Changes in cutoff voltage and in transconductance results from changes in the alinement of tube elements. Intermittent shorts are caused mainly by foreign matter, such as lint or loosened tube parts which are free to move within the tube assembly.

It has been found that by preoperating new tubes in a test rack prior to actual use, many early failures may be eliminated. For preoperation a steady current may be passed through the tube so that the plate and screen operate between one-half and full-rated dissipation. Such preoperation reveals short time changes of tube characteristics, improper emission, inherent mechanical defects, gassy conditions, warping or sagging of grid structures, poor welds, and cracked envelopes. Tubes which survive the first 100 to 300 hours with only minor changes in characteristics are considered good risks for several thousand hours of satisfactory operation in actual equipment.

Tube defects contribute to many equipment failures. For this reason it is good practice for the technician, when troubleshooting equipment, to immediately eliminate any tube known to be faulty. Blind replacement of good tubes by new spares, however, should be avoided. Tubes that have operated for many hours with relatively stable characteristics are more reliable than new tubes just taken out of stock. In general, it is not advisable to replace all the tubes of a group after a predetermined number of hours without regard to their condition. In fact, if the tubes have operated satisfactorily for an appreciable length of time, the intervals between testing may be lengthened. However, certain tubes are notorious for having limited operating lives; in such cases periodic changing will prevent much trouble. The transmit-receive tube used in radar equipment is a good example of a tube that should be changed at regular intervals. In all cases, however, the procedure directed by higher authority must be followed.

CRYSTAL MATCHING

Many pulsed microwave equipments require matched sets of detector crystals for satisfactory operation. The matching of crystals may be accomplished under operating conditions, without elaborate calibration procedures, using normally available test equipment. In this discussion "matching" indicates that if the same amount of pulsed RF energy is applied to two or more detector crystals, the output pulses will not vary by more than a given ratio. If a given signal produces a 0.004-volt peak-to-peak pulse from one crystal and a 0.005-volt peak-to-peak pulse from a second crystal, the ratio is 5 to 4, or 1.2. Converting this to decibels,

$$20 \log 1.2 = 20 \, (0.08) = 1.6 \text{ db}$$

Thus these crystals match within 1.6 db.

A practical method which is usable is indicated in figure 14-3. It is used to measure the calibrated power (supplied by the pulsed signal generator) required to produce a prescribed output (indicated on the oscilloscope). If two crystals require -15.5 dbm and -16 dbm, respectively, to produce a 0.004-volt peak-to-peak pulse, these crystals match within 0.5 db.

The signal generator used will depend on the frequency or frequencies where matching is desired. The crystal holder, bias source, and oscilloscope used will depend upon what is available and what crystals are being matched. Figure 14-3 (B) shows a bias source which may be locally made if a ready-built one (such as the AN/USA-7 unit No. 1) is not available.

TESTING

The term testing, as used in this section, refers to the use of associated equipment to determine or to evaluate the condition or quality of operation of a unit, circuit, or component. Proper testing procedures must begin with the selection of the test equipment. This equipment must be used according to specific instructions. The testing must follow detailed procedures. The results must be evaluated in light of itemized specifications.

The following paragraphs discuss some aspects of the selection of proper test equipment, followed by some special considerations in the testing of certain circuits and components.

SELECTION OF TEST EQUIPMENT

The first requirement of any test equipment is its ability to perform the test required; secondly, it must be compatible with the equipment under test. Chapter 8 of this manual is devoted to a discussion of test equipment. The present discussion is confined to the compatibility between test equipment and the equipment under test, followed by some factors regarding the evaluation of the results of certain tests.

Impedance Matching

Closely associated with circuit loading is the idea of impedance matching. As it pertains to test equipment usage, impedance matching involves the reactive components as well as the resistive component of circuit impedance. For a maximum transfer of power the resistance of the source must equal the resistance of the load and the reactive components must cancel. However, in many testing situations this condition is undesirable.

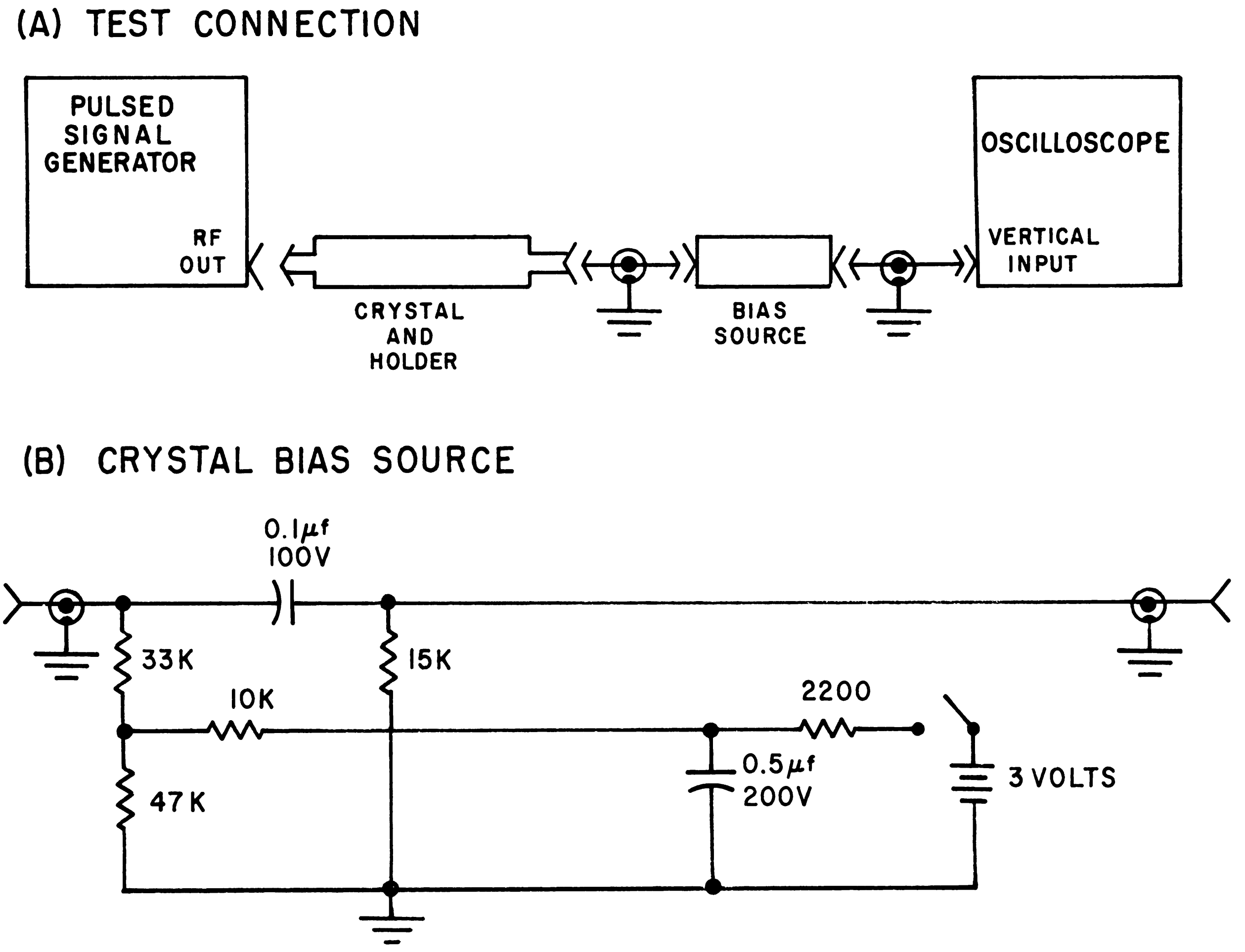

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Figure 14-3.—Crystal matching procedure.

Most items of electronic and test equipment are rated according to input and/or output impedances. Coaxial cables and coaxial adapters are usually supplied with test sets normally used in testing of electronics equipment. The test procedures which govern the use of a specific equipment for a specific test on a specific equipment contain itemized lists of the items required. Use of the specified items provides adequate impedance matching.

As mentioned previously, the cables and fittings supplied with a given test set should be used with that set–substitution of cables frequently causes mismatching of impedance and results in erroneous test results.

Frequency

Another important consideration in the selection of test equipment involves the respective frequency ranges of the test set and the equipment under test. Signal generators must supply frequencies within the response band of tuned circuits; frequency meters must be responsive to the frequencies in the outputs of tuned circuits.

Amplitude

The output signal magnitude of the generator must be large enough to cause a response in the circuit under test. To test the output of that circuit, the test set must have sufficient sensitivity to respond to the signal. In either case, however, signal amplitude must not be so large that it overdrives or damages the equipment. If signals are too large, reduced coupling or increased attenuation may be used to reduce its size. This change must be considered in any evaluation of the test.

Polarity

Many nonsinusoidal signals are used in electronics equipment. Test equipment used in checking circuit operation must be capable of generating (or responding to) the proper polarity input. An example of this requirement is found in the triggering signals of radar synchronizers. Signals having the wrong polarity fail to activate the triggered circuit, and may erroneously indicate a malfunctioning circuit.

CIRCUITS AND COMPONENTS

The most frequently encountered areas of testing are concerned with tubes, tuned circuits, and power measurements.

Testing of Electron Tubes

As previously mentioned, tubes cause more than 50 percent of all electronic equipment failures. The condition of a tube can be determined by substituting a tube known to be good for the questionable one. However, indiscriminate substitution of tubes is to be avoided, as detuning of circuits may result. In addition, a tube may not operate properly in a high frequency circuit, although it performs well in a low frequency circuit. Therefore, in order to service electronic equipment, a knowledge of tube testing devices and their limitations, as well as correct interpretation of the test results obtained, is indispensable for accurate and rapid job performance.

In order to determine the condition of an electron tube, some method of testing is necessary. The operating capabilities (and design features) of a tube are shown by its electrical characteristics. A tube is tested by measuring its characteristics and comparing them with representative values established as standard for that type of tube. Tubes which read abnormally high or low with respect to the standard are subject to suspicion. Practical considerations take into account the limitations of the tube test in predicting actual tube performance in a particular circuit. For most applications the testing of a single tube characteristic is enough to determine whether a tube is performing satisfactorily.

Testing the emission characteristic of the cathode or filament is perhaps the simplest method of determining the condition of a tube. Since emission normally decreases as the tube ages, low emission is normally indicative of the end of tube serviceability. This test is subject to limitations because it tests the tube under static conditions and does not consider the actual circuit operation of the tube. Furthermore, coated cathodes or filaments may develop highly emissive spots, so that the relatively small grid area adjacent to these spots cannot control the electron stream. Under these conditions, testing the total emission may indicate the tube to be satisfactory, while in reality it is defective.

The transconductance (Gm) of a tube used in an amplifier stage is normally a more useful characteristic to measure than the emission. Transconductance is the change of plate current which results from a change in grid voltage. This characteristic, therefore, indicates the ability of the tube to amplify a-c signals. The most common military tube testers provide dynamic transconductance measurements, although some of the testers are limited to static measurements of this characteristic.

It should be kept in mind that a tube-testing device only compares the characteristic of a given tube with a standard for that particular type of tube. Since the operating conditions imposed upon a tube may vary over wide limits, it is not possible for the tube tester to evaluate a tube in terms of performance capability for all applications. Therefore, the tube tester is not always considered the final authority in deciding whether or not a tube is satisfactory. Substituting a good tube in the equipment, and observing the performance of the equipment, provides the most reliable evidence concerning the condition of the tube in question. Substitution is also the only method for testing many high power tubes used for transmitter applications.

Nevertheless, the tube tester plays a very important function in most cases because it provides a quick and satisfactory check on tube serviceability.

Alinement of Tuned Circuits

Tuned amplifier, oscillator, detector, and filter circuits must be properly adjusted for optimum performance of communication and electronic equipment. The signal generator, in conjunction with various indicating devices, is used for most alinement procedures in receiving equipment. Transmitter oscillators can be tuned to the correct frequency by frequency measuring instruments, and transmitter amplifier stages can be adjusted by means of output meters or grid and plate current measurements. However, it is sometimes advantageous to tune transmitter amplifier stages by injecting a known signal from a signal generator in the same manner that receiver amplifier stages are tuned. The type of test equipment necessary for a particular tuning procedure is determined by frequency, power level, accuracy, allowable distortion, and modulation requirements.

The principal purpose of a signal generator is to provide a known signal with adjustable characteristics. There is need, on occasion, for square or other nonsinusoidal waveforms; however, in general, test procedures require the use of sine waves of variable frequency and amplitude.

The need for tuning electronic equipment may be indicated by reduced levels in signal outputs; however, alinement procedures should not be undertaken before general operating tests are made. Every equipment that is operating poorly requires maintenance, but it does not follow that every equipment that needs maintenance also needs alinement. Repairs which require the replacement of parts or the redressing of wiring may make subsequent alinement necessary. Therefore, no alinement should be attempted until all apparent troubles have been corrected and all defective parts replaced. Haphazard attempts at alinement by inexperienced or careless personnel may do more harm than good, and may increase the time required for making relatively minor repairs. Before alinement is attempted, all available instructions should be carefully consulted.

Power Measurement

One very common error in maintenance and in testing is the tendency to underestimate the meaning of decibel readings. As an example, test specifications for a particular portion of the testing procedure of a radar set might call for a decibel reading of 75 db. Upon performing the test in exactly the prescribed manner, it is determined that the decibel reading is 72 db. Too many technicians tend to assume that "this is good enough." It must be remembered, however, that a decrease (in power level) of 3 db represents a 50 percent reduction in power. This condition is intolerable when performing most tests.

SYSTEMS TESTING

Combinations of communication and electronic equipment and facilities are interconnected to form systems capable of performing specific functions. To meet reliability requirements and to comply with operating restrictions, technical personnel must be able to apply general test methods and practices to the installation, tuning, and maintenance of these combinations of equipment and facilities. This may entail a knowledge of many types of communication, and electronic equipment. Radar, communication and fire control equipment, when interconnected, may require different maintenance procedures than when operated separately. Revised test procedures may be necessary, any detrimental interactions between equipment or facilities must be corrected, and effective preventive maintenance must be programed for all equipment and facilities within the system. System quality figures, such as sensitivity and coverage, must be initially determined and measured during equipment preventive maintenance checks to assure efficient operation.

Receiver Sensitivity

The one measurement which provides maximum information about receiver condition in field operation is that of sensitivity. This measurement ordinarily requires the application of an input signal of variable voltage (which is accurately known by calibration) to the antenna terminals of the receiver, through an impedance which approximates that of the antenna with which the receiver is designed to be used. Any external impedance which is added to the signal-generator impedance to simulate the antenna impedance is usually known as a dummy antenna. It insures that the signal current in the input circuit of the receiver is the same as would appear with the known signal induced in an ideal receiving antenna, and it also insures that the input circuit of the receiver is "loaded" the same as it would be by an ideal antenna.

CONDITIONS FOR SENSITIVITY MEASUREMENT.–For measurement of sensitivity, the receiver is adjusted for the type of reception desired, and facilities such as tone controls or audio filters, AGC, silencer, noise limiter, etc., are placed in or out of operation as required or are set at appropriate control positions. The power-line voltage applied to the receiver should be well within the normal recommended operating range. The receiver output terminals should be properly loaded. At the headphone or audio-line terminals, unless otherwise specified in the instruction book for the equipment, the load should be a 600-ohm noninductive resistor (such as one of the composition type) capable of continuously dissipating the maximum receiver audio power output that can be produced at these terminals. High-impedance headphones may be used in shunt with the load for monitoring the output. Low-impedance phones may load the output appreciably and may have to be removed when data are being taken. The output voltage should be measured with a high-impedance audio voltmeter, capable of accurate indication from 0.1 volt to 100 volts, that will not appreciably load the output circuit. Although some receivers are equipped with audio-output meters, the meters provided may not indicate required standard noise levels with sufficient accuracy.

RECEIVER SENSITIVITY (AUDIO-OUTPUT) TESTS.–Receiver output power is measured, as part of a sensitivity test, to determine whether the receiver is performing according to the required sensitivity specifications. (The sensitivity is the value of signal voltage (in microvolts) fed to the antenna terminals that will produce a specified power output–usually 6 milliwatts–at the receiver output terminals with a signal-to-noise ratio of 10:1.) A simple way to check audio-power output is to use an a-c voltmeter (either a copper-oxide-rectifier type or an electronic voltmeter) across a resistor of the correct value, as specified in the instruction manual. With the signal generator delivering an input voltage to the receiver antenna terminals, the voltmeter measures the output voltage across the resistor. The power output is then computed by using the formula $P = E^2/R$.

Transmitter Power Output

Electrical power delivered to a load at any instant is equal to the product of the voltage across the load and the current passing through it, or $P - EI$. Under stable d-c conditions, this product is also equal to the average power consumed. In a-c circuits, on the other hand, the presence of either inductive or capacitive reactance means that the apparent power, EI, where both voltage and current are rms values, must be multiplied by a number called the power factor to obtain the true power. Briefly, this is necessary because pure inductors and capacitors store energy furnished by the line and, during a later portion of the cycle, restore such energy to the line. If purely reactive circuits were possible, none of the power would be dissipated. Naturally, resistance is an unavoidable component of any reactance, so from a strict standpoint nondissipative networks are not attainable. In practical a-c circuits, the power dissipated is equal to the apparent power multiplied by the cosine of the phase angle between the voltage and current.

Calibrated voltmeters and ammeters are used as a direct approach to power measurements in d-c circuits. Usually, approximate indications of power are satisfactory in electronic circuit work, so that neither the expense nor the inconvenience of two separate meters is justified. A typical instance is that of determining whether the power rating of a resistor is adequate. It is generally acceptable to measure the voltage across the resistor and then to calculate the power by the basic equation $P = E^2/R$. For current rather than voltage measurement, the power is equal to I^2R. If the designated resistance of the part is not sufficiently reliable, it may be measured approximately with an ohmmeter. Conceivably, an extremely accurate measurement may be required, in which case a determination by means of a Wheatstone bridge can be made. Similarly, it may be necessary to determine the a-c power dissipated by a resistive load, either at audiofrequency or radiofrequency. The same method is reliable, provided the resistance of the device is known at the frequency in question.

Power Supply Measurements and Adjustments

Power supplies that are commonly used in avionic equipment are either regulated or unregulated. An unregulated supply usually provides filtered but unregulated low B-plus (under 300 v d.c.) or high B-plus (over 300 v d.c.) in addition to a-c heater power for vacuum tubes and in some cases relay-operating power. The regulated power supplies consist of an unregulated supply and the associated circuitry necessary to regulate the B-plus output. Chapter 3 of Basic Electronics, NavPers 10087-B, contains a discussion of power supply operation.

Power supplies used to provide the d-c voltage sources for operation of electronic equipments are of various types, such as half-wave and full-wave rectifiers. The type circuitry employed for a particular application depends on such factors as current and voltage load requirements, available space, weight, degree of voltage regulation required, etc. Electronic systems are generally complex and contain one or more power supplies which provide several voltage outputs. The design performance of these equipments depends upon the proper operation of the power supplies. For this reason, power supply tests are included in the preventive maintenance test procedures prepared for most equipments. Many equipments are provided with easily accessible test points for ease in performing these tests. The more common type of power supply test is a simple voltage reading taken with the equipment in operation.

To operate radar equipment, various d-c voltages are required. The transmitter requires a high voltage source capable of delivering a large current for short intervals of time. The regulation or ripple content of this voltage is not critical. The cathoderay tube requires a high accelerating voltage which is usually easy to regulate because of the low current drain which results in a constant small load. The plate voltage supply for the receiver and the indicator sweep circuits require a source of good regulation and very little ripple. Voltages are also required for relays, blower motors, antenna control motors, etc. Combinations of vacuum tubes, rectifiers, vibrators, transformers, voltage dividers, etc., are used to provide these different voltages.

Power supplies of various types occur throughout the radar system because it is impractical to install all of them in a central location. Even though in some equipments the power supply may lose its identity as a separate unit, the function is still performed and must be tested and maintained at its rated performance.

Intermittent Troubles

Intermittent troubles are probably the most aggravating and irritating problem faced by the technician. The equipment always seems to be in proper operation while under observation, only to malfunction as soon as the technician turns his back. There is no single method for resolving this difficulty. The procedure to be used depends on the individual situation—the technician, the equipment, the available information, the peculiarities of the installation, etc. A thorough knowledge of the operation of the equipment, and an understanding of the most common causes of intermittent troubles should help to alleviate the suffering of the maintenanceman.

Some of the most common causes of intermittent troubles are loose vacuum tube elements, poor electrical connections, poor solder joints, leaky capacitors, arcing, broken terminal boards or printed circuit boards, fused conducting strips, and mechanical vibration. Vibration is usually associated with one or more of the others listed, either as a basic cause or as a contributing factor; therefore it should always be investigated early in the troubleshooting procedure. If the equipment seems to operate properly after a visual inspection fails to reveal the cause of the intermittent trouble, vibrate the equipment by tapping or jiggling while watching for indications of arcing, etc. If this fails to produce meaningful indications, methodical and patient troubleshooting procedures must be followed.

MISCELLANEOUS PROBLEMS

Generally, problems of the mechanical type are caused from excessive wear or carelessness on the part of the technician.

INSTALLATION OF EQUIPMENT

Although itemized installation procedures are listed in the Maintenance Instructions Manual for each model aircraft, and in the Operation and Service Instruction Manual for electronics equipment, this phase of the maintenance process presents a great deal of trouble. Most of the troubles in this category result from carelessness and oversight on the part of the technician. Specific instances are loose cable connections, switched cable terminations, improper bonding, lack of (or improper) safety wiring, remote switches in the wrong positions, failure to perform operational check after installation, failure to pressurize specified units, etc.

Two additional points concerning installation of equipment in aircraft need emphasis. Prior to reinstalling any unit or component, inspect its mounting for proper condition of shock mounts and bonding straps. After installation, safety wire as appropriate.

DISASSEMBLY AND REASSEMBLY

Problems are encountered in the removal and replacement of units in the aircraft and the disassembly and reassembly of subunits in the shop. Some of these problems are considered in this discussion. Most of these problems are created by the technician because of either carelessness or lack of understanding on his part.

One of the problem areas is the threaded fasteners used in the mounting of parts or subunits. Broken or stripped bolts, damaged heads or threads, etc., hamper the disassembly and reassembly process. The use of the proper tools and techniques are very important in keeping this problem to a minimum.

Some units that contain autotune systems that mechanically tune more than one subunit are a problem if these subunits are not properly alined mechanically before insertion into the autotune mechanism. If these subunits have mechanical stops and are inserted into the autotune system improperly, they can be damaged.

Pin or plug alinement before insertion into its mate is necessary if damage is to be prevented. Some of these pins are very small and delicate and will not withstand any bending or distortion without breaking. Some subunits or modules have different pin arrangements though their shell dimensions may be identical; therefore, great care must be taken to insure that the subunits or modules are installed in the proper location.

Coaxial connectors can also be a source of problems. When connecting or disconnecting these connectors, always use great care that the coaxial cable is not separated from the connector. Miniature coaxial connectors can be damaged very easily if handled roughly during connection or disconnection.

ROTATING EQUIPMENT

A great variety of rotating units are employed in naval aircraft. The electrically driven units are usually electric motors. In applications where only small movements are required, solenoids are frequently used (for example, ratchet stepping relays use solenoids).

Although the variety of rotating equipment is great, certain general maintenance procedures are common to the majority of them. Inspections are conducted on rotating equipment as a precaution against failure. Since most rotating units are installed in sections of the aircraft not accessible during flight, the first indication of trouble in many instances is complete failure. When failure occurs or when there are indications that the unit is operating improperly, remove the unit for shop inspection of bearings, commutator and sliprings, and brushes.

Bearings

Antifriction bearings are either ball or roller bearings. These, especially ball bearings, are widely used in aircraft rotating electrical machinery such as dynamotors, inverters, generators, and motor generators. In modern electrical machines, extensive use of sealed bearing assemblies is made. This makes maintenance and lubrication very easy since sealed bearings are prelubricated and require almost no attention during normal operation of the machine in which they are installed.

As a guide to proper maintenance of ball bearings in aircraft rotating equipment, the detailed recommendations of the manufacturer as given in the Service Instruction Manual should always be followed. Excessive lubrication leads to bearing trouble, and an undue amount of grease in the slipring or commutator compartment of the machine may result. Brush and slipring wear increases appreciably if a large amount of lubricant is present. Excessive lubricant should be removed with a cleaning solvent, and the bearings properly lubricated.

Commutators

The connection of the armature conductors to the individual commutator segments is made at the part of the segment referred to as the "riser." This connection is secured by use of hard solder or silver solder. Insulation of all segments from each other and from the armature shaft and core is accomplished by thin sections of mica between each segment and between the segments and the clamps which hold the segments to the shaft. The mica between the segments is cut to the same shape as the segments. That part of the mica directly under the brush is cut below the surface of the commutator bars.

When shop checking, insure that the commutator has a smooth, worn surface around the entire circumference throughout the area spanned by the brushes. It should have an even brown or chocolate color. Any dirt, oil, or grease on the commutator must be removed. Check for brush sparking as evidenced by rough and pitted commutator bars. Look for loose connections to the commutator risers. This may be indicated by specks of solder on the surrounding field coils and connections.

Should the commutator be dirty, it must be cleaned. Oil and dirt tend to glaze the surface with a high-resistance coating. Remove the brushes; blow loose dirt out with air, being careful not to blow it into the housing. Wipe oil and grease out with a lintless cloth moistened with an appropriate cleaning solution.

As the surface of the commutator gradually wears, the mica will eventually become flush with the brush surface of the segments. If this condition is not corrected by undercutting the mica, rapid brush wear is apt to result. Extreme care must be taken when undercutting to prevent the cutting tool from leaving the slot and scoring the brush surface of the commutator; also, great care must be exercised to avoid sharp edges on the commutator bars.

Brushes

The following checks should be made when checking the generator brushes and brush rigging:

1. Look for cracks in the brush holder yoke and check for tightness.
2. Check for loose screws and defective safety wires.
3. Check for loose brush holders and for dirt, grease, and oil.
4. Check for security of jumper leads between holders of like polarity.
5. Check to see that no brush holder is bent out of alinement.
6. Check for broken brush springs.
7. Check the freedom of the brush in the brush holder. The brush should not bind or drag in the holder, but neither should there be enough clearance that a sloppy fit is obtained.
8. Check all brushes for security of the pigtail to the brush and to the terminal, and see that the wire is not worn or frayed.
9. Check the brushes to see that they are not cracked or chipped. Check for pits due to sparking. Check for oil-soaked brushes. If the brush is oil soaked, it must be replaced. The oil acts as an insulator and terminal voltage is lowered.

When reinstalling the original brushes, make certain that they are replaced in their original holders; otherwise, it may be necessary to refit the brushes. When brushes are placed in their holders, the brush springs should be carefully lowered until they make contact with the brush. Never release the brush spring unless it is in contact with the brush since this allows the spring to strike the brush sharply, causing possible damage to the brush. Check for brush wear by measuring the length of the brush. It must be within the limits specified by the manufacturer.

CAUTION: Brushes that have grease and oil on them must be replaced. They cannot be cleaned because a cleaning solvent will not remove all of the oil or grease and will change the electrical characteristics of the carbon. The brush holders and brush rigging should be cleaned before inserting the new brushes.

When it becomes necessary to install new brushes, the following procedure is recommended. Pull brush springs back only as far as necessary to allow removal of old brushes; this may be easily done by using a hook made of stiff wire. Attach brush pigtails of new brushes to proper connections and secure electrically. Insert brushes in brush holders. After the new brushes have been installed, steps must be taken to remove the old commutator film, fit the new brushes, and establish a new film.

For this purpose, a brush seater should be used. (Never use emery paper or any other kind of paper or cloth containing a metallic abrasive.)

The brush seater consists of a mildly abrasive material loosely bonded and formed in the shape of a stick about 5 inches in length. The brush seater is applied to the commutator while the machine is running, and therefore every precaution must be taken to prevent injury to the person applying it. The brush seater is applied lightly, for a second or two, exactly at the heel of each brush (fig. 14-4).

If the seater is placed even one-fourth inch away from the heel of the brush, only a small part of the abrasive will pass under the brush. Pressure is applied to the brush by setting the brush spring tension at maximum (during the seating operation) or by pressing a stick of insulating material against the brush. Dust is removed during the operation, and the machine is thoroughly cleaned afterwards.

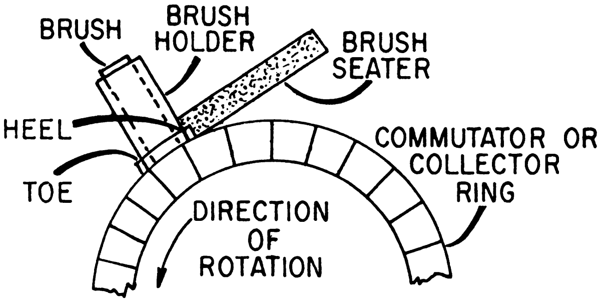

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Figure 14-4.–Using the brush seater.

Sliprings

Sliprings must be inspected periodically for smoothness of surface, diameter of the rings, and alinement of the rings on the shaft. The sliprings require the same careful attention as a commutator. Out-of-round conditions of the rings may be corrected in the same manner as for commutators, except for the fact that crocus cloth is used to apply a mirror-like finish following any turning or grinding operations.

CHAPTER 15

DIGITAL COMPUTERS

Present and future technicians will be faced with a collection of electronic equipments which use computers as integral portions of the overall system. To understand the operation of the system in general, and the computer portion in particular, it is necessary to have a basic understanding of computer functions, circuitry, terminology, and applications. Basic Electronics, NavPers 10087-B, chapter 16, presents a basic coverage of the purpose, operation, and theory of computers, together with some of the terminology peculiar to them. Review and study of these basic coverages will aid in understanding the material covered in this chapter.

INTRODUCTION TO DIGITAL COMPUTERS

In the past few years, the term digital computer has appeared in Navy nomenclature. This term refers to an electromechanical device which is used in applications such as fire control, communications, and tactical data processing. Digital computers accomplish things that were impossible before, and they speed up processes which formerly required considerable time. Although the operations of computers are not new, the techniques of electronics have made possible a computer contained in a small, lightweight package which is adaptable to aircraft systems. Also, prior to the incorporation of electronics in digital computers, the great speed of operation required was impossible with purely mechanical devices.

The technician of today is faced with equipments which have the computer used as an integral part of the overall system. Therefore, the technician must have a basic understanding of computer functions, the circuitry involved, the numbering system used, and computer terminology.

The definition of a computer is: Any device capable of accepting information, applying mathematical operations to that information, and obtaining useful results of these operations. Therefore, a computer must have an input, processing, and output section.

Before any problem can be solved by a computer, the quantities involved must be expressed in terms of common units; that is, digital computation is the process in which digits alone are used to solve the problem.

Basically, the purpose of a digital computer is the same as that of any other computational aid. However, it is more accurate within practical limits of speed. Computers can perform thousands of repetitive computations involving hundreds of thousands of digits without making an error. Further, they can store millions of items of information for future use.

Digital computers also have limitations in that a continuous variable cannot be processed. Simple and explicit instructions (programing) must be provided for each operation that is to be performed. Instructions as to where information is stored, how to use it, what to do with it, and what step is required next are sometimes more complicated than the problems the computer is used to solve. Approximations and rounding off are also problems encountered with computers.

A digital computer performs its calculations by counting and comparing. With this simple capability, it can add, subtract, multiply, divide, and make logical decisions. Therefore, to perform computations with a digital computer, all that is needed is the provision of a method which will enable the machine to count, compare, and transfer a digit from one place to another. Therefore, before a discussion of computer devices, it is necessary to learn the language of the computers.

NUMBERING SYSTEMS

While there are many different numbering systems, this discussion will deal with only two; that is, the base ten (decimal) and base two (binary) systems. The binary system will be compared with the decimal system because most computers utilize the binary system and most readers understand the decimal system. The bistable nature of simple electronic components such as switches (open or closed) and tubes and transistors (conducting or cutoff) makes the binary numbering system quite usable.

In the decimal system there are ten digits used (0 through 9), and in the binary system there are two digits used (0 and 1). The symbols or digits used are repeated as many times as desired or needed. Both systems also use the place value or positional notation concept. This means that a numeral has a specific value by virtue of its position.

An example of place value is shown in the two numbers 230 and 203. The 3 has a different value in each numeral by virtue of its position.

POSITIONAL NOTATION

In the previous example the numeral 230 when stated by the reader to be two hundred thirty, some assumptions are made which must be understood in order to compare the decimal and binary systems.

The first assumption the reader made was that when the number 230 was first looked upon, the number was assumed to be a decimal number. When no base symbol is given, the decimal system is assumed. If the number had been a base four number, it would have been written as $230_{(4)}$ with the 4 indicating the base of the numbering system. Some examples and their numbering base symbols are as follows:

Number	Base
398	ten (decimal)
$342_{(5)}$	five (quinary)
$101_{(2)}$	two (binary)

Therefore, when a number is written in base ten, no base indicator is given. If the number is written in a base other than ten, the base indicator is used.

Another assumption made is that the number 230 is two hundred thirty; that is, the digit 2 indicates hundreds, the digit 3 indicates tens, and the digit 0 indicates units. In base ten, this is true. The digits have specific values according to their position. Place value or positional notation for the number 378924 in the decimal system is as follows.

Place value	10^5	10^4	10^3	10^2	10^1	10^0
	100000	10000	1000	100	10	1
number	3	7	8	9	2	4

Notice that the place value column on the right is 10° or 1. The increasing place values, moving to the left, are indicated by the base (10) raised to one greater power. The second place value column is, then, 10^1, the third is 10^2, etc.

The number 378924, then, is

$$3(100000) + 7(10000) + 8(1000) + 9(100) + 2(10) + 4(1)$$

The place value columns for the binary (base two) system follow the same pattern as the base ten system except the base two is used.

For example, the number $10110_{(2)}$ is indicated in the place value chart for base two as follows:

Place value	2^4	2^3	2^2	2^1	2^0
	16	8	4	2	1
Number	1	0	1	1	0

The number $10110_{(2)}$, then, is

$$1(16) + 0(8) + 1(4) + 1(2) + 0(1) = 22_{(10)}$$

Notice that place value in base two has a different value than the same place in base ten.

COUNTING IN BASE TWO AND BASE TEN

In base ten, when counting from 0, the numbers are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9.

The next number to be counted is ten, but there is no single symbol in base ten to indicate the next number. Therefore, a combination of symbols is used by repeating the 0 and indicating a 1 in the tens column. This means one group of tens and no groups of units.

When counting in base two, there are only two digits or symbols; that is, 1 and 0. The same mechanical process is used in base two that was used in base ten. Starting with 0, in base two, the count is 0, 1.

There are no other symbols to indicate the next number so a 1 is written in the next place value column to the left and a 0 is written in the first place value column; that is, 0, 1, $10_{(2)}$.

This last number, then, indicates one group of two and no groups of units. The next number is $11_{(2)}$ which means one group of twos and one group of units. A number such as $1101_{(2)}$ would indicate one group of eights, one group of fours, no group of twos, and one group of units, and in this case is the same as decimal number 13.

Counting comparisons between the decimal and binary systems are made as follows:

Decimal	Binary
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111
16	10000
17	10001

Notice that when counting objects, the decimal 17 and binary 10001 refer to the same object; therefore, decimal 17 must be equivalent to binary 10001.

CONVERSIONS

If the binary number 101 is to be converted to a decimal number, the binary number is written in expanded notation; that is

$$101_{(2)} = 1(4) + 0(2) + 1(1)$$

and the indicated multiplication, by terms, is carried out and yields

$$4 + 0 + 1 = 5$$

The 5 is a base ten number; that is, if objects were counted in a row and stopped with the decimal 5 and then the same objects were counted again in binary, the same object would be indicated with one-zero-one ($101_{(2)}$).

Example: Convert $11101_{(2)}$ to base ten.

Solution: Write $11101_{(2)}$ in expanded notation as

$$1(16) + 1(8) + 1(4) + 0(2) + 1(1)$$

and carry out the multiplication to obtain

$$16 + 8 + 4 + 0 + 1 = 29$$

Problems: Convert the following binary numbers to base ten.

1. 111
2. 1001
3. 11111
4. 1000001

Answers:

1. 7
2. 9
3. 31
4. 65

To convert the decimal number 26 to binary, first intuitively determine the largest place value column contained in the number; that is, in the place value chart

2^5	2^4	2^3	2^2	2^1	2^0
32	16	8	4	2	1

there is one group of 16 or 2^4 in 26. Also, there must be five digits in the representation of 26 in binary because the place value column for 2^4 is the fifth place value column from the right. This is indicated by drawing lines for each digit as follows:

2^4	2^3	2^2	2^1	2^0
—	—	—	—	—

There is one group of 16 in 26; therefore, write

2^4	2^3	2^2	2^1	2^0
1	—	—	—	—

Sixteen is indicated leaving 26 - 16 to be accounted for, or ten. There is one group of 2^3 in ten so write

2^4	2^3	2^2	2^1	2^0
1	1	—	—	—

After accounting for one group of 16 and one group of 8, 2 is left. There are no groups of 2^2 in 2 so write

2^4	2^3	2^2	2^1	2^0
1	1	0	—	—

and then find there is one group of 2^1 in 2 and write

2^4	2^3	2^2	2^1	2^0
1	1	0	1	—

leaving 0. Finally there is no group of 2^0 in 0 so write

2^4	2^3	2^2	2^1	2^0
1	1	0	1	0

Therefore, 26 in decimal is equal to 11010 in binary.

This type conversion is quite complicated in dealing with large numbers. There is a technique which enables us to convert from decimal to binary quite simply by continual division of the decimal number by the base of the binary system, indicating the remainder after each division operation until the quotient is zero. This is shown in the following:

Convert 26 decimal to binary–

2 |26
13 remainder is 0
2 |13
6 remainder is 1
2 |6
3 remainder is 0
2 |3
1 remainder is 1
2 |1
0 remainder is 1

The remainders are read from the bottom to the top to obtain the binary equivalent of the decimal number; that is;

$$26 = 11010_{(2)}$$

The division process may be combined as follows:

Convert 38 to binary–

2 /38
2 /19 0
2 /9 1
2 / 4 1
2 / 2 0
2 / 1 0
0 1

and the binary equivalent of 38 is $100110_{(2)}$.

Problems: Convert the following decimal numbers to binary.

1. 29
2. 624

Answers:
1. 11101
2. 1001110000

BINARY ARITHMETIC

Familiarity with the basic arithmetic operations in the binary system is needed in order to enhance the understanding of computers;

therefore, a comparison between the decimal and binary systems will be discussed.

Addition

When counting in the decimal system, a limit is reached where the next number cannot be indicated in a single column; that is,

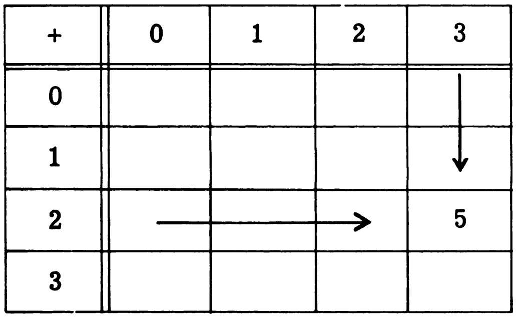
0
1
2
3
4
5
6
7
8
9

At this point a "carry" is made; that is, the first digit (0) is repeated and a 1 is indicated in the tens column. This means one group of tens and no groups of units, and is indicated by 10.

The ADDITION facts of the DECIMAL system are shown in the truth table below:

+	0	1	2	3	...
0	0	1	2	3	...
1	1	2	3	4	...
2	2	3	4	5	...
3	⋮	⋮	⋮	⋮	

for example:



means

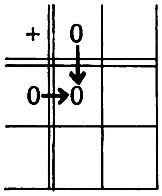
2 + 3 = 5

Binary addition is similar to decimal addition, except in binary only two digits, 0 and 1, are available. The mechanical procedure is the same.

The ADDITION facts of the BINARY system are as follows:

+	0	1
0	0	1
1	1	10

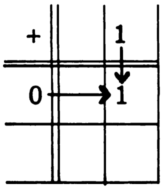
That is,



means

0 + 0 = 0

and



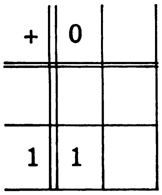
means

0 + 1 = 1

or

1 + 0 = 1

and



means

1 + 0 = 1

or

$$0 + 1 = 1$$

and

+		1
1		10

means

$$1 + 1 = 10$$

This means that

$$\begin{array}{l} 0 + 0 = 0 \\ 0 + 1 = 1 \\ 1 + 0 = 1 \\ 1 + 1 = 10 \end{array}$$

When adding numbers in base ten, the following mechanical procedure is followed:
Add 172 and 32

$$\begin{array}{rl} 172 & \\ \underline{+\ 32} & \\ 104 & \text{partial sum} \\ \underline{+100} & \text{carry overs} \\ 204 & \text{final sum} \end{array}$$

When adding two binary numbers, the process is

$$\begin{array}{rl} 0101 & \\ \underline{+0111} & \\ 0010 & \text{partial sum} \\ \underline{+1010} & \text{carry overs} \\ 1000 & \text{partial sum} \\ \underline{+0100} & \text{carry overs} \\ 1100 & \text{final sum} \end{array}$$

The previous addition may be stated as follows:

Starting from the right column, one plus one equals 0 and 1 carry. The carry plus zero plus one equals zero and one carry. The carry plus one plus one equals one and one carry. The carry plus zero plus zero equals one.

Problems: Add the following binary numbers.

1. 1001 and 101
2. 1101 and 1111

Answers:
1. 1110
2. 11100

Computer Addition

The computer technique of addition utilizes the process of half add, carry, and final sum. Half add means to add two digits and neglect the carry. The carry is written below the half add sum and then added to this half add sum. An example in decimal is as follows:
Add 3562 and 2149

$$\begin{array}{rl} 3562 & \\ \underline{+2149} & \\ 5601 & \text{half add} \\ \underline{+0110} & \text{carry overs} \\ 5711 & \text{final sum} \end{array}$$

If other carry overs are required, they are handled as follows:
Add 4965 and 5247

$$\begin{array}{rl} 4965 & \\ \underline{+\ 5247} & \\ 9102 & \text{half add} \\ \underline{+\ 1110} & \text{carry overs} \\ 0212 & \text{half add} \\ \underline{+10000} & \text{carry overs} \\ 10212 & \text{final sum} \end{array}$$

Problem: Add the following, indicating half adds and final sums.

1. 9328 and 6973
2. 9323 and 739

Answers:
1. 5291 half add
   16201 half add
   16301 final sum
2. 9052 half add
   0062 half add
   10062 final sum

The computer technique is used in binary as it is used in decimal.

Example: Add the binary numbers 11101 and 1101.

Solution:

```
   11101
+   1101
   10000  half add
+  11010  carry overs
   01010  half add
+ 100000  carry overs
  101010  final sum
```

Example: Add the binary numbers 1101 and 110.

Solution.

```
   1101
+   110
   1011  half add
+  1000  carry over
   0011  half add
+ 10000  carry over
  10011  final sum
```

Problems: Add the following binary numbers indicating half adds and final sums.

1. 110 and 10
2. 11011 and 111

Answers:

1. 100 half add
   000 half add
   1000 final
2. 11100 half add
   11010 half add
   10010 half add
   00010 half add
   100010 final sum

Subtraction

Both the direct and complement method of subtraction will be discussed. The methods will also be compared in the decimal and binary systems.

DIRECT SUBTRACTION.–In the decimal system, when subtractions are made, the terms to be subtracted are named as follows:

```
 7  minuend
-2  subtrahend
 5  difference
```

In cases where the subtrahend, in a particular column, is greater than the minuend, a borrow must be made; that is, a digit must be moved from a higher place value column to a lower place value column. An example is

```
 76
-39
```

where 9 is to be subtracted from 6.

In this case one group of tens must be borrowed from the 7 group of tens. This is shown by

```
 76
-39
```

is

```
    10
  6  6
 -3  9
```

and 9 from 16 is 7. Therefore,

```
  6  16
 -3   9
   37
```

This concept may be applied to as many columns as necessary. For example, in the problem

```
 9326
-7438
```

one group of tens is borrowed from the two groups to give

```
       10
  931   6
 -743   8
        8
```

then one group of hundreds is borrowed from the three groups to give

```
      10  10
  92   1   6
 -74   3   8
       8   8
```

The next step is

$$\begin{array}{rrrr} & 10 & 10 & 10 \\ 8 & 2 & 1 & 6 \\ -7 & 4 & 3 & 8 \\ \hline & 8 & 8 & 8 \end{array}$$

and finally

$$\begin{array}{rrrr} & 10 & 10 & 10 \\ 8 & 2 & 1 & 6 \\ -7 & 4 & 3 & 8 \\ \hline 1 & 8 & 8 & 8 \end{array}$$

The subtraction problem difference may be verified by adding the difference to the subtrahend to give the minuend. This shown by

$$\begin{array}{r} 1888 \\ +7438 \\ \hline 9326 \end{array}$$

Binary subtraction problems are solved in the same manner as decimal subtraction problems except base two is used. One fact may cause problems; that is, when 1 is subtracted from 0, the difference is 1 if a borrow of 1 is made. An example of this is shown by the following:

$$\begin{array}{r} 10 \\ -\ 1 \\ \hline \end{array}$$

A borrow of 1 is made, to give

$$\begin{array}{rr} & 10 \\ 0 & 0 \\ - & 1 \\ \hline \end{array}$$

10 (which must be read as "one-zero," and not as "ten") in base two is really 2 in decimal, and 1 from 2 is 1. Therefore,

$$\begin{array}{rr} & 10 \\ 0 & 0 \\ - & 1 \\ \hline & 1 \end{array}$$

When no 1 is available in the next higher place value column, a higher place value column must be used. This is shown in the following example of binary subtraction:

$$\begin{array}{r} 100 \\ -\ \ 1 \\ \hline \end{array}$$

A borrow from the 2^2 column is made, giving 10 in the 2^1 column.

$$\begin{array}{rrr} & 10 & \\ 0 & 0 & 0 \\ - & & 1 \\ \hline \end{array}$$

Then, a borrow of 1 is made from the 10 in the 2^1 column, leaving 1 in this column and giving a 10 in the 2^0 column, and 10 minus 1 is 1,

$$\begin{array}{rrr} & & 10 \\ 0 & 1 & 0 \\ - & & 1 \\ \hline \end{array}$$

Therefore,

$$\begin{array}{rrrl} & & 10 & \\ 0 & 1 & 0 & \text{minuend} \\ - & & 1 & \text{subtrahend} \\ \hline 0 & 1 & 1 & \text{difference} \end{array}$$

Verification of this difference is made by adding the subtrahend to the difference to yield the minuend.

$$\begin{array}{r} 011 \\ +\ \ 1 \\ \hline 100 \end{array}$$

Problems: Find the difference in the following binary subtraction problems.

1. $\begin{array}{r} 101 \\ -\ 10 \\ \hline \end{array}$

2. $\begin{array}{r} 10101 \\ -\ \ 111 \\ \hline \end{array}$

Answers:

1. 11
2. 1110

SUBRACTION BY COMPLEMENTS (BASE TEN).–Digital computers are generally unable to perform subtraction in the manner previously discussed because the process of borrow involves operations which are impractical to incorporate into a machine. The process which involves complements is used in digital computers. By complement, it is meant the number or quantity required to fill or complete something. The complement of a number is, therefore, another number which completes the original number with respect to a known reference.

For example, the nines complement of a number is that number when added to the original number that will yield all nines in the place value columns used. An example of this is as follows:

What is the nines complement of 32?

What number, when added to 32, will produce 99?

Intuitively, it can be seen that the number is

$$99 - 32$$

or

$$67$$

If one is now added to the nines complement, the tens complement results; that is,

$$67 + 1 = 68$$

and 68 is the tens complement of 32. Notice that if 68 is added to 32, the sum is 100. Therefore, the tens complement of a number is defined as that number which, when added to the original number, yields a 1 in the next high place value column and zeros in all other columns. The tens complement of 78 is

$$100 - 78 = 22$$

Notice that the tens complement is in reference to a power of ten one place value higher than the highest place value of the original number.

Number	Tens complement	Reference
7	3	10^1
21	79	10^2
309	691	10^3

Rather than subtract the subtrahend from the minuend, the tens complement of the subtrahend (found with reference to the power of ten one place value higher than either the subtrahend or minuend) may be added to the minuend and then decrease this sum by the reference power of ten used to obtain the difference. A step-by-step process is shown to explain the preceding statement.

Example: Subtract 26 from 49

Solution: Write

$$\begin{array}{r} 49 \\ \underline{-26} \end{array}$$

then find the tens complement of 26 which is

$$100 - 26 = 74$$

This may be rearranged as follows:

$$100 - 74 = 26$$

Now, instead of writing

$$49 - 26$$

write

$$\begin{aligned} & 49 - (100 - 74) \\ &= 49 - 100 + 74 \\ &= 49 + 74 - 100 \\ &= 23 \end{aligned}$$

This indicates that the minuend (49) plus the tens complement of 26 (that is, 74) are added, then the reference power of ten used (100) is subtracted to give the difference which is 23. Notice that

$$\begin{aligned} & 49 - 26 \\ &= 49 + 74 - 100 \\ &= 123 - 100 \\ &= 23 \end{aligned}$$

the digit (1) found in the place value column higher than the highest place value column of the subtrahend had only to be dropped. Generally, this digit (1) which is developed indicates the difference (23) is a positive value.

Example: Subtract 36 from 429

Solution: Write

$$\begin{array}{rl} 429 & \text{minuend} \\ -\ 36 & \text{subtrahend} \end{array}$$

then

429 minuend
+ 964 tens complement of subtrahend
1¦393
= +¦393 remainder

The process of subtracting a larger number from a smaller number, using the tens complement, is slightly different from the example previously shown. Instead of developing a 1 in the higher place value column, a zero will be present. The complement of the apparent remainder will indicate the actual negative remainder.

Example: Subtract 362 from 127

Solution: Write

127 minuend
- 362 subtrahend

then

127 minuend
+ 638 tens complement of subtrahend
0¦765 apparent remainder
= -¦235 tens complement of apparent remainder

which is

- 235 actual negative remainder

SUBTRACTION BY COMPLEMENTS (BASE TWO).–Digital computers use the complementary addition technique for subtraction, which has been discussed in decimal notation; and they also use the base two system. The process for base two is similar to base ten.

The ones complement of a binary number is that number with all 1 digits changed to 0's and all the 0 digits changed to 1's. This process is termed inversion. Therefore, the ones complement of 10110 is 01001. The twos complement of a binary number is its ones complement plus 1; that is,

Number	Ones complement	Twos complement
01	10	11
111	000	001
1110	0001	0010

Notice that the number 01 plus its twos complement 11 equals 100 which is a 1 in the next higher place value column followed by zeros.

The twos complement may also be determined by inverting every digit after the first one (1); that is, starting with the smallest place value and moving toward the largest place value (right to left). This method is normally less time consuming than determining the ones complement and then adding one to form the twos complement. For example: the twos complement of

001101011¦10
← invert all ¦
is
110010100¦10

The first one (from right to left) does not invert.

This indicates that the same procedure used for decimal numbers may be used for binary numbers to perform subtraction by the addition of the complement.

Problems: Find the ones and twos complements of the following binary numbers.

1. 101
2. 101101

Answers:

	Ones complement	Twos complement
1.	010	011
2.	010010	010011

Example: Subtract the binary number 01101 from the binary number 11001.

Solution: Write

11001 minuend
- 01101 subtrahend

then

11001 minuend
+ 10011 twos complement of the subtrahend
1¦01100 difference
= +¦01100 positive difference

Notice that the same number of place value columns must be used in both the subtrahend and minuend.

Example: In binary, subtract 1110 from 1111.

Solution: Write

1111	minuend
- 1110	subtrahend

then

1111	minuend
+ 0010	twos complement of the subtrahend
1¦0001	difference
= +¦0001	positive difference

As in the decimal system, if a one is developed, it indicates plus. If a zero is present, it indicates a negative apparent answer and the complement of the apparent answer is used, preceded by a minus sign.

Example: In binary, subtract 1011 from 1001.

Solution: Write

1001	minuend
- 1011	subtrahend

then

1001	minuend
+ 0101	twos complement of the subtrahend
0¦1110	apparent difference
-¦0010	twos complement of the apparent difference
= -¦0010	negative difference

Problem: Subtract in binary, using complementary addition.

1. 1101 from 1110
2. 111 from 10

Answers:

1. +0001
2. -101

A verification of the preceding problems may be made by changing the binary numbers to decimal, carrying out the subtraction, then changing the difference back to binary.

This is as follows:

	binary		decimal
1.	1101	=	13
	1110	=	14

and

$$14 - 13 = 1 = 1_{(2)}$$

	binary		decimal
2.	111	=	7
	10	=	2

and

$$2 - 7 = -5 = 101_{(2)}$$

Multiplication

The direct method of multiplication of decimal numbers is shown in the following example.

Example: Multiply 32 x 25

Solution: Write

$$25 = 20 + 5$$

then

$$32\ (20 + 5)$$

Using the distributive principle

$$\begin{aligned} & 32\ (20 + 5) \\ &= 32\ (20) + 32\ (5) \\ &= 640 + 160 \\ &= 800 \end{aligned}$$

The same problem written as

$$\begin{array}{r} 32 \\ \underline{\times 25} \end{array}$$

gives

32 x 5
= 160 partial product

and

32 x 20
= 640 partial product

then

160 + 640
= 800 product

The technique generally used is

$$\begin{array}{r} 32\\ \underline{\times\ 25}\\ 160\\ \underline{64}\\ 800 \end{array}$$

Notice that the 64 really represents $64\underline{0}$, but the zero is omitted.

Direct binary multiplication uses the same technique as direct decimal multiplication.

Example: Multiply the following binary numbers.

110 and 1101

Solution: Write

$$\begin{array}{r} 1101\\ \underline{\times\ \ 110}\\ 0000\\ 1101\\ \underline{1101}\\ 1001110 \end{array}$$

This may be verified by changing the factors to decimal, multiplying and obtaining the decimal product, then changing the decimal product back to binary.

Problems: Multiply the following pairs of binary numbers.

1. 11 and 101
2. 11011 and 1011

Answers:

1. 1111
2. 100101001

Repetitive Addition

The idea that multiplication is repetitive addition is of beneficial use when working with computers. When multiplication is to be accomplished with a computer, the process of repeated addition is used.

If two numbers are to be multiplied together, write the following:

Multiply

231 by 45

Write

$$231\ (40 + 5)$$

then

$$(231 \times 40) + (231 \times 5)$$

Multiplying each term gives the following:

$$\begin{array}{r} 231\\ \underline{\times\ 40}\\ 9240 \end{array} \quad \text{and} \quad \begin{array}{r} 231\\ \underline{\times\ 5}\\ 1155 \end{array}$$

Notice that 231 could have been added forty (40) times to satisfy one half of the above problem and 231 could have been added five (5) times to satisfy the other half.

$$\left.\begin{array}{r} 231\\ 231\\ 231\\ 231\\ \text{''}\\ \text{''}\\ \text{''}\\ \\ \underline{+\ 231} \end{array}\right\}\ 40 \text{ times} \qquad \left.\begin{array}{r} 231\\ 231\\ 231\\ \\ 231\\ \underline{+\ 231} \end{array}\right\}\ 5 \text{ times}$$

$$\begin{array}{r} 9240 \end{array} \qquad\qquad\qquad \begin{array}{r} 1155 \end{array}$$

Rather than write 231 forty times, 2310 could have been written four times; that is,

$$\begin{array}{rl} & 231 \times 40\\ = & 231 \times 4 \times 10\\ = & 231 \times 10 \times 4\\ = & 2310 \times 4\\ \\ = & 2310\\ & 2310\\ & 2310\\ & \underline{+\ 2310}\\ & 9240 \end{array}$$

$$9240 + 1155 = 10395$$

When the repetitive addition type of multiplication is used in a computer, it would appear as follows. Two registers are used; that is, the accumulator and the multiplier. The accumulator maintains a constant subtotal and the multiplier keeps account of the addition to be performed.

The problem is to multiply 231 by 45.

Accumulator	Multiplier	
000000	45	
+ 000231		
000231	44	These operations represent the five ones
+ 000231		
000462	43	
+ 000231		
000693	42	
+ 000231		
000924	41	
+ 000231		
001155	40	These operations represent the four tens
+ 002310		
003465	30	
+ 002310		
005775	20	
+ 002310		
008085	10	
+ 002310		
0010395	00	

Notice that the multiplier indicated the number of times the number 231 was added and the accumulator maintained the subtotal. When the multiplier indicated 40, the 231 was changed to 2310 and the multiplier then would indicate addition of the 2310 four times. The overall effect was to move the zero in the 40 to the 231.

The binary system follows the previous techniques as shown in the following example. Multiply 1011 by 1101.

Accumulator	Multiplier
00000000	1101
+ 00001011	
00001011	1100
+ 00101100	
00110111	1000
+ 01011000	
10001111	0000

Division

The direct method of division of decimal numbers is shown in the following example:

Example: Divide 30 (dividend) by 5 (divisor).

Solution: Write

$$5\,\overline{)\,30}$$

Five is not contained in 3 but is contained in 30. How many 5's are contained in 30? The answer is 6, so write 6 above the zero

$$\begin{array}{r} \underline{6} \text{ (quotient)} \\ 5\,\overline{)\,30} \end{array}$$

Multiply the 6 and 5 together and find the product which is 30. Write 30 under the 30 and subtract.

$$\begin{array}{r} 6 \\ 5\,\overline{)\,30} \\ \underline{30} \\ 0 \end{array}$$

There are no 5's in zero; therefore, the answer is 6.

Direct binary division follows the same procedure.

Example: Divide 1110 by 111.

Solution: Write

$$111\,\overline{)\,1110}$$

There is one 111 in 111 so write 1 above the right hand one in 111 as follows:

$$\begin{array}{r} 1 \\ 111\,\overline{)\,1110} \end{array}$$

Multiply 111 by 1 and write the product under the 111, and subtract, and bring down the last zero.

$$\begin{array}{r} 1 \\ 111\,\overline{)\,1110} \\ \underline{111} \\ 0000 \end{array}$$

There are no 111's in 0000; therefore, write zero after the 1 in the answer and find 10 is the answer.

```
        10
111 / 1110
      111
         0
         0
```

Example: Divide 10010 by 110, all in binary.
Solution: Write

```
          1
110 / 10010
```

Multiply quotient and divisor and subtract from dividend.

```
          1
110 / 10010
      110
       11
```

Bring down last zero.

```
          1
110 / 10010
      110
       110
```

Find 110 goes into 110 one time and write

```
         11
110 / 10010
      110
       110
```

Multiply quotient and last dividend digit and find

```
         11
110 / 10010
      110
       110
       110
       000
```

and the answer is 11.

Problems: Divide the following binary numbers.

1. 10010 by 110
2. 10000111 by 101

Answers:

1. 11
2. 11011

Repetitive Subtraction

In multiplication, repeated addition is used; in division, repeated subtraction is used.

If one number (the dividend) is to be divided by another number (the divisor), write the following:

Divide 126 by 6
Write

```
126
- 6
120
- 6
114
- 6
108
- 6
 ''
 ''
```

Subtracting 6 from 126 twenty-one times registers a zero remainder.

A computer does the same thing except it utilizes powers of ten.

Use is still made of the accumulator and register as in repetitive addition but the technique is operated in reverse order.

Example: Divide 40320 by 126.

Accumulator	Quotient register	
40320		(a) Put the dividend in the accumulator.
	0000	(b) Set the register to zero.
-12600		(c) Put the divisor in the largest power of ten that is equal to or less than the value of the dividend that is in the accumulator.
	+0100	(d) Put the power of ten into the register.
27720		(e) Subtract.
	+0100	(f) Add the sums in the quotient register.

Accumulator	Quotient register	
-12600	+0100	(g) Repeat steps (c), (d), (e), and (f) as shown.
15120	0200	
-12600	+0100	
2520	0300	
- 1260	+0010	
1260	0310	
- 1260	+0010	
0000	0320	Answer.

Example: Divide 126 by 6.

Accumulator	Quotient register	
126	000	
- 60	+010	
066	010	
- 60	+010	
006	020	
- 6	+001	
000	021	Answer

The same procedure applies to binary division except the highest power of 2 (in binary) is used.

Example: Divide 100111 by 11.

Accumulator	Quotient register	
100111	00000	
- 11000	+01000	Add 2^3 to quotient register.
1111	01000	
- 1100	+00100	Add 2^2 to quotient register.
11	01100	
- 11	+00001	Add 2^0 to quotient register.
0	01101	Answer

CODING

As stated previously, electronic circuit elements of computers are inherently binary; that is, they will have two stable states. Therefore, the base ten numbering system cannot be used efficiently in computers. While people communicate and calculate using letters of the alphabet and numbers of the decimal system, digital computers communicate and calculate using groups of binary symbols called codes.

Coding is the means by which data in one form is represented in another form which is acceptable to the computer. A form of coding is used in the Morse code in which letters are represented by dots and dashes. This makes the alphabet acceptable to transmission by radio.

Of the many coding systems, three of the most common ones are discussed. It should be understood that memorization of these codes is not necessary, but the understanding of the reasons for the codes is desirable.

BINARY CODED DECIMAL (B.C.D.)

This code makes use of groups of binary bits (binary symbols) to represent a decimal digit. In the decimal system there are only ten digits; therefore, only ten groups of binary bits must be remembered. EACH DECIMAL DIGIT IS REPRESENTED BY A GROUP OF FOUR BINARY BITS. The ten groups to remember are as follows:

Decimal digit	Binary - coded decimal digit			
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

To write ten in B.C.D., the use of two groups is required; that is,

Decimal	1	0
B.C.D.	0001	0000

Any two-digit decimal number requires two groups of B.C.D. etc.

Decimal	7	3	8
B.C.D.	0111	0011	1000

The separation of the B.C.D. groups is shown for ease of reading and does not necessarily need to be written as shown; 738 could be written as 011100111000. One advantage of the B.C.D. over true binary is ease of determining the decimal value. This is shown as follows:

B.C.D.	0111	0011	1000
= decimal	7	3	8

738 in true binary is 1011100010
and, true binary 1011100010
= decimal $1(2^9) + 0(2^8) + 1(2^7) + 1(2^6)$
$+ 1(2^5) + 0(2^4) + 0(2^3) + 0(2^2)$
$+ 1(2^1) + 0(2^0)$
= 512 + 128 + 64 + 32 + 2 = 738

The ease of converting from decimal to B.C.D. and from B.C.D. back to decimal should be apparent in the following.

Problems: Convert the following decimal numbers to B.C.D.

1. 7
2. 4200

Answers:

1. 0111
2. 0100001000000000

Problems: Convert the following B.C.D.'s to decimals.

1. 010000110001
2. 0101000001111000

Answers:

1. 431
2. 5078

The comparative ease of conversion in B.C.D. is related to the difficulty of conversion in true binary by the following.

Problems: Convert

1. 438 to binary
2. 100101101 to decimal

Answers:

1. 110110110
2. 301

One serious disadvantage of the B.C.D. is that this code cannot provide a decimal carry. The following examples are given to show this.

Example: Add the following:

Decimal		B.C.D.
5	=	0101
+ 3	=	0011
8	=	1000

Notice that there was no carry in the decimal addition and the answer in B.C.D. is equal to the answer in decimal. The B.C.D. is in correct notation and does exist.

Example: Add the following:

Decimal		B.C.D.
8	=	1000
+ 5	=	0101
13	=	1101

Notice that the B.C.D. answer is correct in true binary, but $1101_{(2)}$ does not exist in B.C.D. The correct B.C.D. answer for 13 should be 0001 0011. Therefore, when a carry is made in decimal, the B.C.D. cannot indicate the correct answer in B.C.D. form.

Excess Three Code

The excess three code is used to eliminate the inability of the binary carry. It is really a modification of the B.C.D. so that a carry can be made.

To change a B.C.D. number to excess three, add three to the B.C.D.; that is,

B.C.D.	1000
	+ 0011
Excess three	1011

In excess three code 1011 is 8 in decimal. The following chart shows the decimal, B.C.D., and the excess three code.

Decimal	B.C.D.	Excess three
0	0000	0011
1	0001	0100
2	0010	0101
3	0011	0110
4	0100	0111
5	0101	1000
6	0110	1001
7	0111	1010
8	1000	1011
9	1001	1100

As previously stated, the excess three code will provide the capability to carry in binary. The following is given for explanation.

Example: Add $6_{(10)}$ and $3_{(10)}$ in excess three.

Solution: Write

Decimal		Excess three with three groups possible		
6	=	0011	0011	1001
+ 3	=	0011	0011	0110
9				

Notice that in group one the six and three are indicated. In groups two and three a zero (0011) in excess three is indicated.

Add as follows

0011	0011	1001	(Excess three)
0011	0011	0110	(Excess three)
0110	0110	1111	(Excess six)

But our answer is in excess six. Therefore, three must be subtracted from each group in order to return our answer to excess three.

0110	0110	1111	
-0011	-0011	-0011	
0011	0011	1100	(Excess three)
0	0	9	Answer in decimal

When a carry is developed in any group, the following procedure is used.

Example: Add $9_{(10)}$ and $3_{(10)}$ in excess three.

Solution: Write

Decimal	Excess three				
9	0011	0011	1	1100	(Excess 3)
+3	0011	0011		0110	(Excess 3)
12	0110	0111		0010	(Excess 6)

NOTE: Since group one created a carry, as shown, three must be added instead of subtracted in order to place group one into excess three. The other groups follow the previous example.

0110	0111	0010	(Excess six)
-0011	-0011	+0011	
0011	0100	0101	(Excess three)
0	1	2	

The above procedure will hold for any number of group indicators the computer possesses.

Problems: Add the following numbers using excess three and give the answers in excess three with three indicator groups.

1. 5 and 3
2. 4 and 3
3. 58 and 77

Answers:

1.	0011	0011	1011
2.	0011	0011	1010
3.	0100	0110	1000

A further advantage of excess three code is the ease with which the nines complement of a number indicated in excess three may be found; that is, the nines complement of 7, indicated in excess three as 1010, is found by inverting each digit in 1010 to read 0101. This 0101, in excess three, is 2 which is the nines complement of 7.

The following table shows the nines complement of the decimal digits:

Decimal	Excess three	Excess three inverted	Nines complement
0	0011	1100	9
1	0100	1011	8
2	0101	1010	7
3	0110	1001	6
4	0111	1000	5
5	1000	0111	4
6	1001	0110	3
7	1010	0101	2
8	1011	0100	1
9	1100	0011	0

GRAY CODE

This code is a modification of the binary counting system. In the Gray code sequence counting, only one bit will change as each count proceeds. When counting in binary from $7_{(10)}$ ($0111_{(2)}$) to $8_{(10)}$ ($1000_{(2)}$), notice that four bits had to be changed.

The Gray code is shown for comparison.

Decimal number	Pure binary	Gray code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111

In the Gray code when counting from $7_{(10)}$(0100) to $8_{(10)}$(1100), notice that only one bit changed.

One of the primary purposes of this code is the reduction of operational errors by changing only one digit at the time during the process of converting mechanical changes into numerical expressions. For example, to convert the shaft rotation (output of an analog computer) from seven to eight degrees would require only a change of one bit as previously indicated.

To convert a binary code to its Gray code equivalent, the following addition WITHOUT CARRY is used.

Example: Convert binary 0100 to its Gray code equivalent.

Solution: Keep the most significant bit as is.

Binary 0 1 0 0
Gray 0 _ _ _

Next, add horizontally the most significant bit to the next significant bit in the binary number and carry the sum to the Gray code as follows:

Binary 0 1 0 0
Gray 0 1 _ _

now add and continue as shown

Binary 0 1 0 0
Gray 0 1 1 _

then

Binary 0 1 0 0
Gray 0 1 1 0

Therefore, 0100 binary is equivalent to 0110 in the Gray code.

Example: Convert $14_{(10)}$ to Gray code.

Solution: Write

Decimal 14 = 1110 binary
Binary 1 1 1 0
Gray 1 _ _ _

then

Binary 1 1 add without the
Gray 1 0 _ _ carry

then

Binary 1 1 1 0
Gray 1 0 0 _

then

Binary 1 1 1 0
Gray 1 0 0 1

therefore, 1110 binary is equivalent to 1001 in Gray code.

Problems: Convert the following decimal numbers to the Gray code.

NOTE: This transition must include the binary code.

1. 12
2. 35

Answers:

1. 1010
2. 110010

A method is also needed to convert Gray code to binary code.

Example: Convert 1101 in Gray code to binary.

Solution:

Gray 1 0 0 1 Retain the most significant
Binary 1 _ _ _ Gray code bit.
Gray 1 0 0 1 Add diagonally without a
Binary 1 1 _ _ carry.

Gray 1 0 $\textcircled{0}$ 1 Continue diagonal addition.

Binary 1 $\textcircled{1}$ $\underline{1}$ _

Gray 1 0 0 $\textcircled{1}$ Continue.

Binary 1 1 $\textcircled{1}$ $\underline{0}$ Therefore, Gray 1001 is equivalent to binary 1110.

Problems: Convert the following gray codes to binary.

1. 10000
2. 0001

Answers:

1. 11111
2. 0001

OCTAL NUMBERS

Octal numbers are base eight numbers; that is, there are only eight digits in base eight. These are 0, 1, 2, 3, 4, 5, 6, and 7. Because eight is a power of two, the octal system has special characteristics that make it especially useful in situations involving binary numbers. This is illustrated as follows:

A decimal number can be converted to octal by the same method described for decimal to binary; that is, to change 334 to octal write

	Remainder
8 /334	
8 /41	6
8 /5	1 ↑
0	5

Therefore,

334 decimal = 516 octal or $516_{(8)}$

The same decimal number when changed to binary is 101001110.

Since things equal to the same thing are equal to each other

$$516_{(8)} = 101001110_{(2)}$$

Notice that the true binary number is separated into groups of three digits from the right as follows:

101 001 110

and by observation, notice that each group represents the following:

101 001 110

5 1 6

which is 516 in octal.

To convert from binary to octal, it is only necessary to divide the binary number into groups of three and read each group as the octal representation in place value.

To convert from octal to binary, the reverse operation is used; that is,

5 1 $6_{(8)}$

101 001 110

Example: Convert 40 decimal to octal, then to binary.

Solution: Write

	Remainder
8 /40	
8 /5	0 ↑
0	5

Therefore,

$$40_{(10)} = 50_{(8)}$$

and then

$50_{(8)}$

101 000

The preceding conversions from binary to octal and from octal to binary are possible because 2^3 is the same as 8^1.

Problems: Convert the following binary numbers to octal.

1. 101101
2. 1110110

Answers: (In base eight)

1. 55
2. 166

Problems: Convert the following octal numbers to binary.

1. 482
2. 761

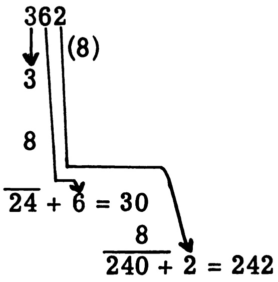
Answers: (In binary)

1. Impossible to have an 8 in base eight (is not an octal number).
2. 111110001

The octal number system affords many conveniences. When recording a binary number on paper, it is usually more convenient to write it in octal. For example, computer programers and programing manuals use the octal system as a convenient notation for binary numbers. Also, when converting a large decimal number to binary, it is usually more convenient to convert it to octal first and then to binary since fewer divisions are required in dividing a decimal number by 8 instead of 2.

A number in any base that is smaller than ten can be converted to a number in base ten (decimal) by the following method: Multiply the most significant digit (MSD) by the present (old) base, add the next MSD to the product of the last multiplication and multiply the sum by the present (old) base, continuing until the least significant digit (LSD) is added.

EXAMPLE: Convert
to decimal



INPUT AND OUTPUT DEVICES

An analog device yields an output in the form of a varying voltage, current, resistance, or mechanical shaft rotation. This form of output is unusable as an input to a digital computer. Since the majority of military indicating devices are of the analog type, their outputs must be converted to be used as inputs for the digital computers.

INPUT DEVICES

An input device is considered to be any device which yields an output which is usable for the particular computer it feeds. The devices which will be discussed are referred to as converters or encoders because they convert analog information into digital information.

V-Scan Converter

The V-scan converter continuously converts a changing mechanical position (analog information) into pulses (binary information) with an accuracy of plus or minus one bit (binary digit).

The basic method of converting a mechanical position into a binary code involves an arrangement of brushes and contacts. The mechanical movement positions the brushes relative to the contacts. The conducting contacts contain a voltage level which represents a binary 1 and the insulating contacts contain no voltage which represent a binary 0. The contact arrangement necessary to produce a natural binary code ranging from 0 to 15 is illustrated in figure 15-1.

NOTE: For the purpose of discussion, consider the contact arrangement in figure 15-1 as being attached on the side of a tank containing a liquid. The brushes are controlled by the level of the float which varies with the level of the liquid in the tank. Notice that, as shown, when the brushes move downward, a binary indication of the amount of liquid expended is indicated. The dark areas are conducting contacts and the light areas are insulating contacts. The four squares at the top of the contact arrangements represent four in-line brushes. The position of the in-line brushes, as shown, indicate a binary 0000 or zero. The analog output moves the brushes down the contacts to indicate any binary number from 0000 (zero) to 1111 (fifteen).

Unfortunately, there is an ambiguity associated with the use of the in-line brushes and the natural binary code. This problem arises at any point where two or more brushes are required to switch at the same moment from one type of contact to the other; that is, from conducting to insulating or from insulating to conducting.

Figure 15-2 shows a portion of a four-bit binary coding plate and reveals the exact nature of the problem. Note that the brush positions that are indicated by x's are reading a 6 (0110). At this instant the brushes are obviously providing the correct reading. Ex-

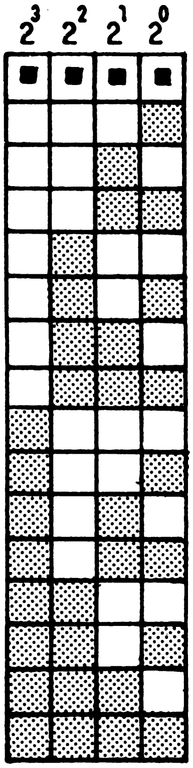


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Figure 15-1.—Natural binary code contact arrangement.

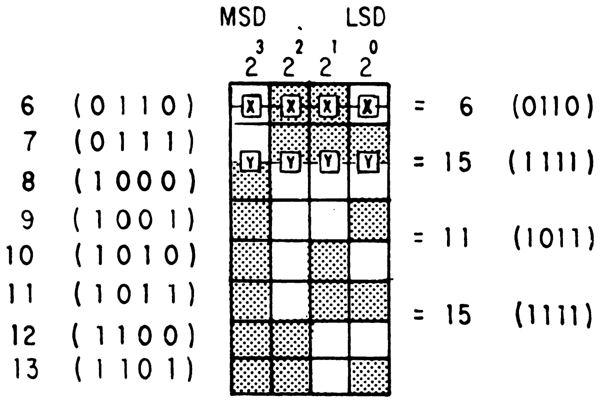

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Figure 15-2.—Ambiguity with the natural binary code.

amination of the next position of the brushes, indicated by y's, however, reveals ambiguous readings. For this example, the brush position is at the switching point from 7 (0111) to 8 (1000). The brush in the 2^3 column is making contact with the conducting material, while brushes in the 2^0, 2^1, and 2^2 columns are still making contact with the conducting material. The output from the brushes at this time is 15 (1111), which should not occur when moving from 7 (0111) to 8 (1000). This produces an erroneous reading. Note that erroneous readings are also obtainable at the 9 to 10 switching point and at the 11 to 12 switching point.

Obviously, the possibility of reading a 15 when it should actually be switching from 7 to 8 (or reading 11 when it should be switching from 9 to 10, or of reading any of the other ambiguous numbers that may be produced) makes it impossible to read instantaneous values with any high degree of certainty. The major factors in determining the accuracy of the natural binary-coded converter are the positioning of the contacts, the positioning of the brushes, the size of the contacts, and the thickness of the brushes. The perfect converter, in order to preclude ambiguities, would have each contact exactly in its required position, all brushes in a straight line perpendicular to the direction of movement, all contacts exactly the same size, and the brushes infinitesimally narrow and exactly uniform. Meeting the prestated requirements for a perfect converter is a physical impossibility.

The V-scan converter employs a method of conversion whereby the physical requirements allow almost perfect conversion. This is accomplished by the use of a double brush (except for the 2^0 column brush) system. The particular relationship between the brushes is predetermined. The direction of movement to be used when describing one set of brushes as leading and one set of brushes as lagging is determined by the design of the grid. In figure 15-3 the direction which will determine the leading or lagging brushes is downward. This direction must be used regardless of whether the float is causing the brushes to move downward or upward. This may occur when filling or emptying the tank.

When reading the brush positions from right to left, two rules are followed:

1. If a bit is read as a one (electrical contacts touching) in a place value column, the

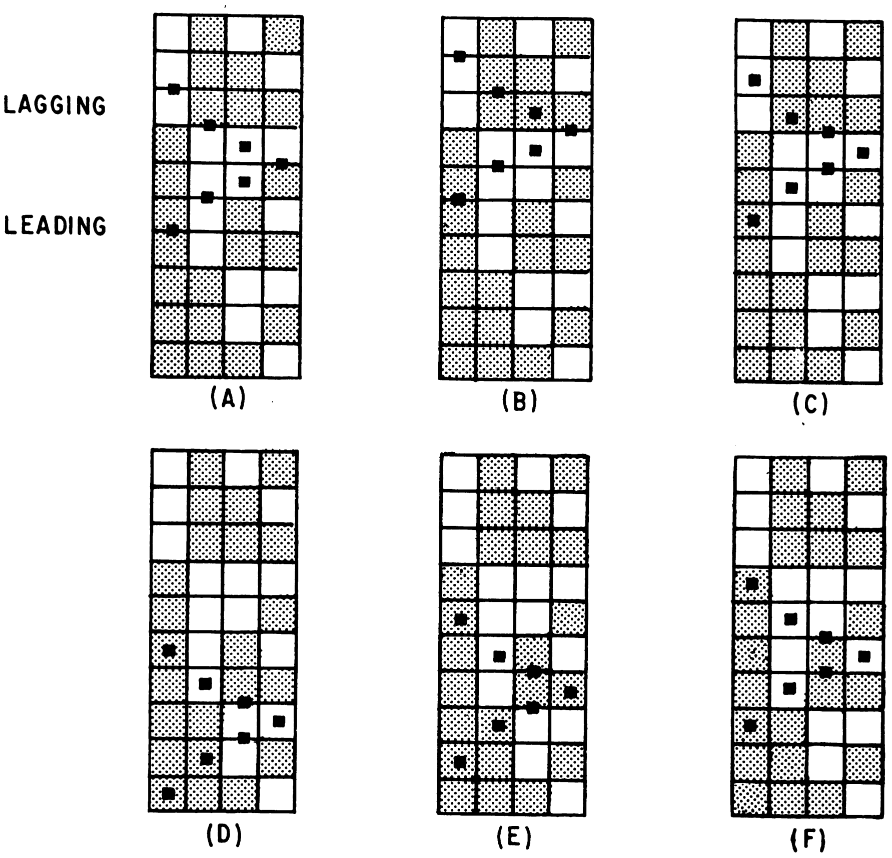

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Figure 15-3.–Natural binary code contact arrangement showing V-scan brushes.

next larger place value column is read on the lagging brush.

2. If a bit is read as a zero (nonconducting contact) in a place value column, the next larger place value column is read on the leading brush.

The determination of whether a leading or lagging brush is used at any particular time is a design function of this converter and will not be discussed.

Since the least significant digit (LSD) column has but one brush, it will always be the reference. As shown in each section of figure 15-3, there are some brushes that are touching conducting and nonconducting segments at the same time. By applying the previously stated rules, figure 15-3 (A) is read as follows:

Column 1: This is our reference brush and since it is conducting a binary 1 is read.

Column 2: Read the lagging brush position because column 1 brush was conducting. The lagging brush position indicates a zero.

Column 3: Read the leading brush position because column 2 brush was not conducting; therefore, a zero is read for column 3.

Column 4: Read the leading brush position which indicates a zero. Therefore, figure 15-3 (A) is indicating $1001_{(2)}$ or $9_{(10)}$.

The following sections of figure 15-3 indicate:

Figure 15-3 (B) - $0111_{(2)}$ or $7_{(10)}$

Figure 15-3 (C) - $1000_{(2)}$ or $8_{(10)}$

Figure 15-3 (D) - $1100_{(2)}$ or $12_{(10)}$

Figure 15-3 (E) - $1011_{(2)}$ or $11_{(10)}$

Figure 15-3 (F) - $1010_{(2)}$ or $10_{(10)}$

BINARY WHEEL.–The binary wheel is a basic application of converting shaft rotation (analog) to binary (digital) information.

The binary wheel is a plane comprised of concentric circles, with each ring divided into twice as many sectors as the adjoining inner ring. A close examination of figure 15-4 will show that it is really the previous rectangular set of contacts (fig. 15-2) set up in concentric rings. If the brushes are located in a straight line, as shown in figure 15-4, the same difficulty of erroneous indications will be present as the brushes move around the circles.

By installing dual brushes in all rings except the outer (least significant digit) ring, as shown in figure 15-5, and properly placing the brushes, the erroneous readings may be eliminated. The number indications are read as previously indicated for the V-scan readings. The direction of rotation of the disk determines which set of brushes will be leading or lagging–in this case, clockwise.

Binary Gray Coded Grid

Figure 15-6 shows a grid (coded in the Gray code) with five brushes. The shaded blocks indicate 1 binary, and the blank blocks indicate 0 binary. This is the same as previously used. Notice that as the brushes (x) more down the

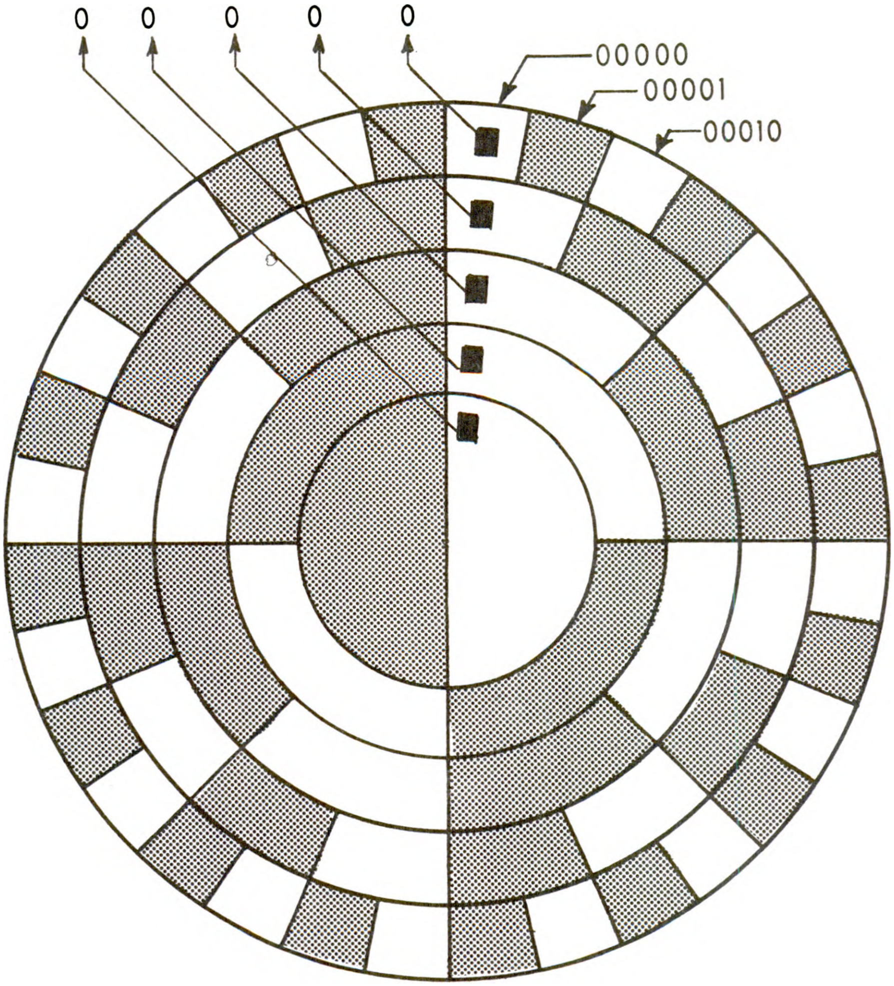

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Figure 15-4.–Simple five-bit shaft encoder.

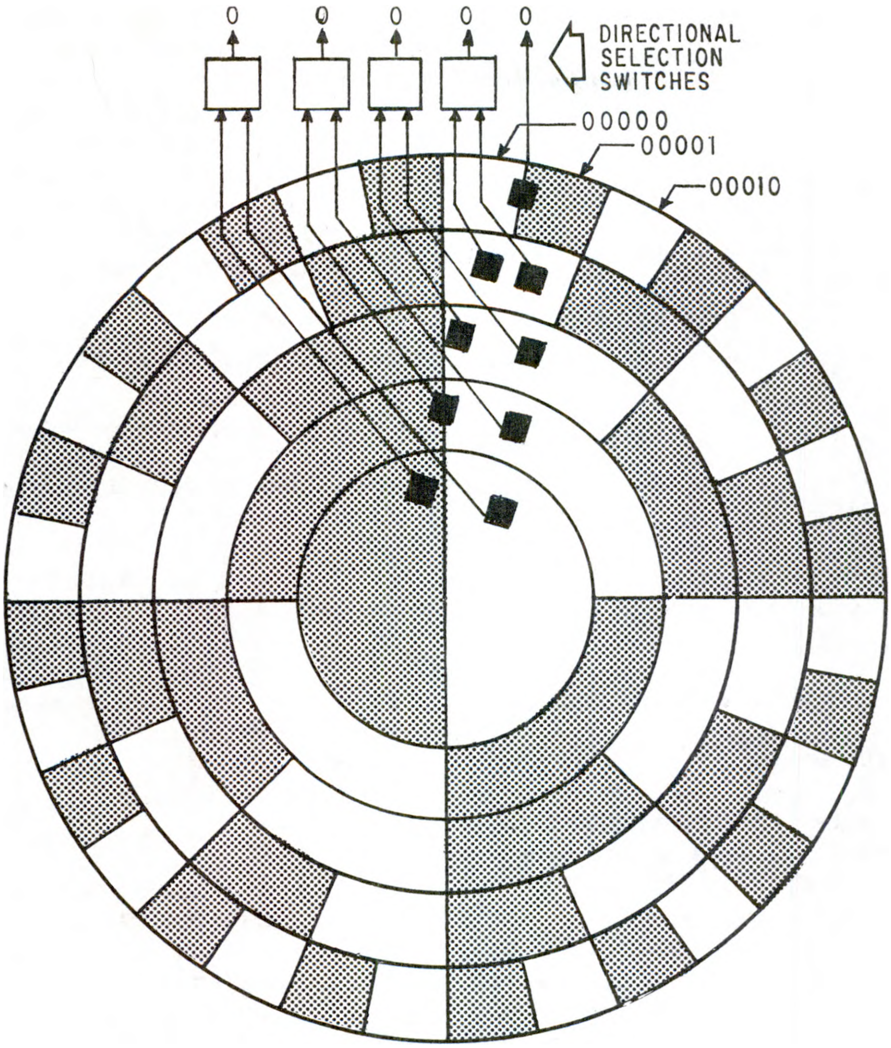

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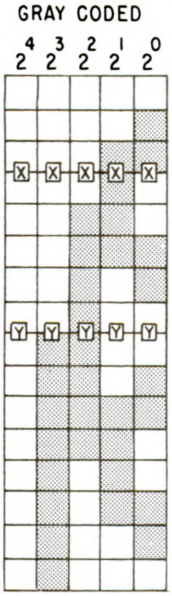
Figure 15-5.–Five-bit V-scan encoder.

grid, only one brush will change its state (conducting to nonconducting or nonconducting to conducting) as the number is increased by one.

The brushes are shown to be indicating two in Gray binary; and as they move to 3 Gray binary, only one brush changed state. In figure 15-2 the movement from 7 to 8 caused an erroneous reading. Notice that as the brushes (y) shown in figure 15-6 move from 7 to 8, an erroneous reading does not occur because only one brush changed state.

BINARY GRAY CODED WHEEL.–Figure 15-7 shows the binary Gray coded wheel in which angular position of the brushes is represented by a Gray coded number. In changing from one number to the next, only one brush changes state. Notice that one set of brushes allows indications in sequential steps without ambiguous readings when moving from one number to the next.

In figure 15-7, the brush reading line shows the reading to be 01001 in Gray code. This indication could represent bearing, speed, direction, or any of many analog positions.



GRAY	BINARY	DECIMAL
00000	0 0 0 0 0	0
00001	0 0 0 0 1	1
00011	0 0 0 1 0	2
00010	0 0 0 1 1	3
00110	0 0 1 0 0	4
00111	0 0 1 0 1	5
00101	0 0 1 1 0	6
00100	0 0 1 1 1	7
01100	0 1 0 0 0	8
01101	0 1 0 0 1	9
01111	0 1 0 1 0	10
01110	0 1 0 1 1	11
01010	0 1 1 0 0	12
01011	0 1 1 0 1	13
01001	0 1 1 1 0	14
01000	0 1 1 1 1	15

AQ.201

Figure 15-6.–Binary Gray coded grid.

Brush Encoder Problems

The disadvantages of brush type encoders are early and frequent failures caused by excessive brush and disk wear, frequent miscounting, critical brush alinement, and low operating speeds. Brushes are susceptible to vibration and acceleration forces that can cause intermittent contact and shifts in brush position. High rotational speeds cause wear of the brushes and particle contamination of the code disk, which lead to a diminution of accuracy. Brush bounce at high speeds may be severe, resulting in extraneous pulse outputs. Although a compromise may be reached by an increase in brush-contact pressure, this also increases the load torque, aggravates the problem of wear of the brush contacts, and reduces life of the code wheel. The results are encoders which are unreliable, have a short useful life, require frequent and costly maintenance and/or replacement, and are limited in operating speed.

Optical Encoders

In optical encoders, there are no contacting surfaces other than bearings. Photocells are used to detect light from a light source through a code disk which has alternately opaque and transparent segments. Electronic amplifying, discriminator, and logic circuitry is required to optain the desired digital output. Continuous low-voltage d-c tungsten lamps are usually used as the light source, which has a predicted life of over 10,000 hours. The mean-time-between-failure (MTBF) of optical encoders is at least 10 times greater than that of comparable brush encoders.

OUTPUT DEVICES

Input and output devices are similar in operation but perform opposite functions. It is through the use of these devices that the computer is able to communicate.

Output information is also made available in three types: human information, such as codes or symbols presented on a cathode-ray screen which are used by the operator to answer questions or make decisions; information which operates a control device such as a lever, aileron, or actuator; or information which is stored in a machine language or human language, on tapes, or printed media.

Wheel Displays

Any one of the angle to number converters previously described can be connected as an output device, either to furnish an angle signal or display (pointer or servo signal) or to mechanically position a particular symbol on a wheel display. The symbol to be displayed can be any arbitrary number, letter, word, or other symbol selected by the designer.

The wheel can be positioned by a servomotor, by a step counting switch, by a digital to analog converter coupled with a motor, etc. The only limitation on the positioning system is that it must be able to drive the wheel until the correct symbol is displayed.

The display may be generated by wheels geared together in a fixed ratio (as in an odometer) or with each wheel individually driven and positioned. A disadvantage of the second system is the increased space required to accommodate the separate drive mechanisms. The number of symbols to be displayed is limited by the size of the wheel and by the number of discrete positions that can be selected.

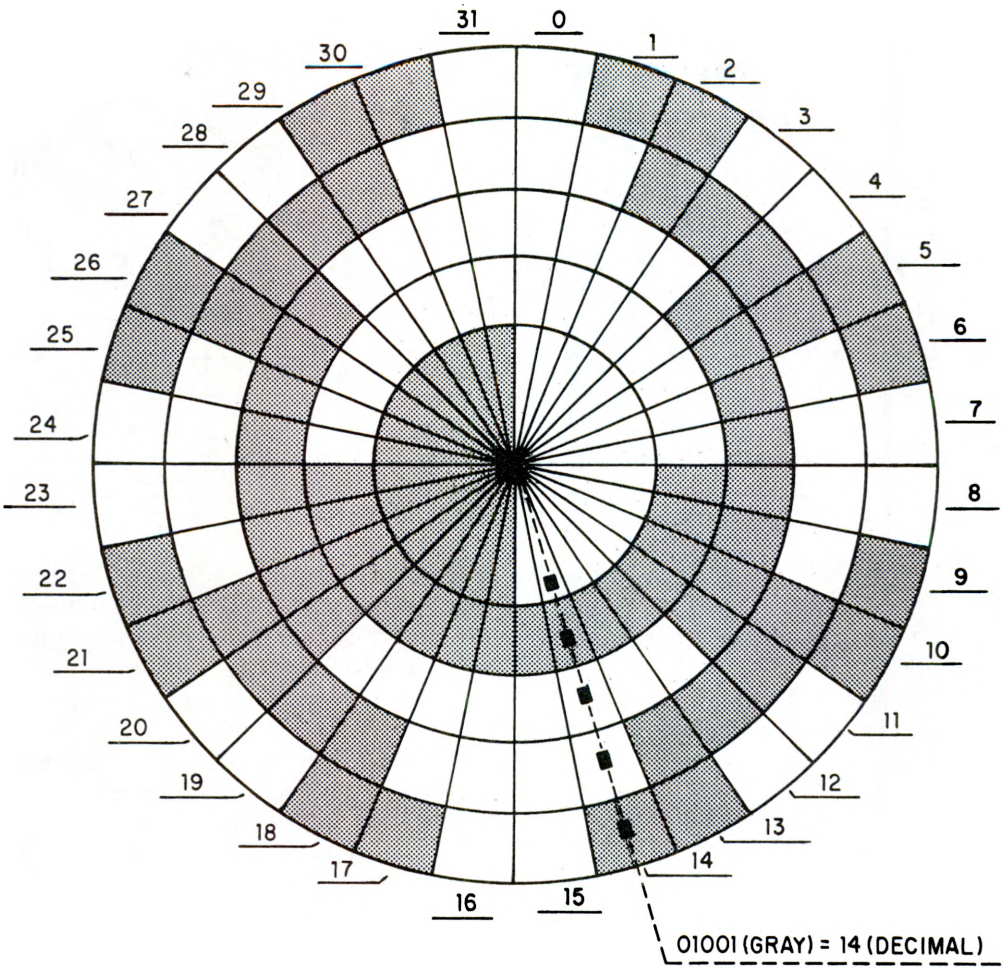


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Figure 15-7.–Binary Gray coded wheel.

Practically any encoder can be used as a decoder (digital-to-analog converter) either directly or by positioning it with a null-seeking driver.

Lights

Each individual light may be considered as the equivalent of a binary stage: ON–true or one; OFF–false or zero. Lights are used to display such discrete data as failsafe, on-off, and warning. They may be used in groups and in conjunction with ring counters to form binary to decimal conversion displays. Each individual light is sequenced and illuminates the appropriate digit when switched on by the counters. (See fig. 15-8 (A).)

MULTIFILAMENT LIGHTS.–These lights may display numbers, letters, symbols, or combinations of these. Filaments may "edge light" lucite cards to illuminate engraved symbols, or may actually be shaped in the form of the symbol and glow when switched on. (See fig. 15-8 (B) and (C).)

Lights require appreciable current–greater than that which is normally available directly from the computing circuits. Therefore, a buffer or amplifier stage is usually required to furnish the additional current. Since a single display illuminates multiple symbols and requires at

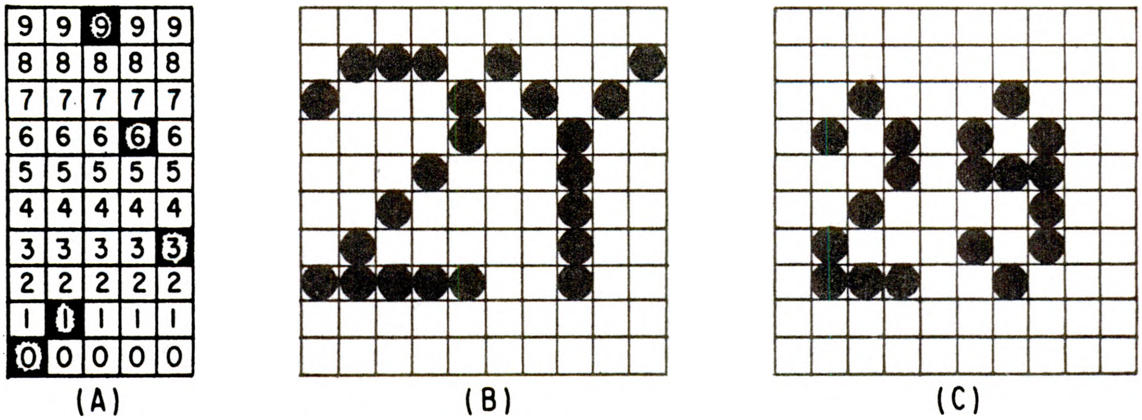

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Figure 15-8.–Light displays.

least one terminal for each, it may require its own counter circuits to convert from binary code to the display code, or it may share a common converter with several other circuits. On the other hand, the individual filaments may be prewired to a printed circuit board, and the appropriate display selected and switched by computer circuitry.

The value or quantity being measured may be represented by a positioned display of multiple filament lights. The digital voltmeter is a fairly common example of the use of these lights.

APPLICATIONS

Digital computers are finding increasingly wide application in Navy aircraft. Some aircraft now operational, and others that will become operational in the near future, have computers installed as integral parts of the electronics system. Among the more common applications in Navy aircraft at present are the navigation systems, weapon delivery systems, tactical communications systems, ASW and ECM systems, and automatic flight systems.

The digital computer receives problems involving distinct and fixed numerical quantities, and produces the solution of these problems also as distinct and fixed quantities; that is, for a specific problem, the digital computer produces one specific answer which is based on the data supplied to the computer. If any factor in the problem is varied, it must then be treated as a new and different problem and the entire problem must be recomputed.

The digital computer expresses magnitude as a number of digits, and its accuracy is limited only by the number of significant figures provided. Increased accuracy can be obtained by utilizing more significant figures. The basic principle of operation of any digital computer is simply the process of counting.

The ability to make calculations is built into the computer by using appropriate combinations of relatively simple circuits. A computer also has the ability to retain information by storing it in memory banks. This information, fed to the computer by an operator, must be available whenever the operator calls for it.

When a computer performs an operation, it does so by comparing quantities representing data that have been placed into it. Its output consists of data that must be "read" and automatically translated into some form of understandable language.

There are two types of digital computers. The special purpose computer, designed to do a limited number of jobs, has a memory that is fixed (usually wired in). The general purpose computers, like the Univac, are capable of many jobs; but their circuitry, while fundamentally the same as that of the special purpose computer, becomes very complex when considered as a whole.

Instructions are stored in the memory unit by a process called "readin." These instructions may be changed simply by reading in the desired new set of instructions. General purpose machines have great flexibility because of the ease with which the instructions may be changed; thus, they are able to do many jobs.

CHAPTER 16

COMMUNICATION FACILITIES, PRINCIPLES, AND EQUIPMENT

DISTRESS FREQUENCIES AND PROCEDURES

The assignment of radiofrequencies is an extremely important problem. Increasing use of the radiofrequency spectrum, by civilian as well as military communicators, means that the portions of the spectrum available for Navy use are limited.

Maximum economy in frequency usage is therefore essential and must be constantly exercised by assignment authorities. To prevent harmful interference, thorough coordination of frequency usage is essential. Coordination of frequency usage, by international agreement, is a responsibility of the constitutional authority of the governments concerned. In the case of active theaters of operations, however, this responsibility rests with the theater commander. In other areas where the national authorities consider it expediant, coordination of military assignments is normally undertaken by frequency coordination committees. Committees have been established in areas throughout the world to arrange for speedy and satisfactory coordination of frequency assignments with a minimum of interference.

The publication which outlines distress procedures and frequencies is Communications Instructions Distress and Rescue Procedure, ACP135 (current edition). This Allied Communication Publication (ACP) was developed for allied use. The sections of this ACP which are of particular interest to the technician are reviewed briefly in part in the following paragraphs.

INTERNATIONAL DISTRESS FREQUENCIES

The following list contains certain frequencies which are especially important:

1. 500 kHz–International Calling and Distress, preferably A2 (MCW) or B (damped wave) for aircraft, or survival craft using frequencies in the band from 405 kHz to 535 kHz when requesting assistance from the maritime services. It is used for the distress call, distress traffic, urgency signal, and safety signal.
2. 2182 kHz–Maritime Mobile Service Calling and Distress, for radiotelephone stations working in the authorized bands between 1605 kHz and 2850 kHz.
3. 8364 kHz–International Lifeboat, Liferaft, and Survival Craft, for operators equipped to transmit on frequencies between 4000 kHz and 23,000 kHz who wish to establish communications relating to search and rescue.
4. 121.5 MHz–International Aeronautical Emergency, for aircraft and those aeronautical stations primarily concerned with the safety and regulation of flights using national or international civil air routes and operating in the band between 118 MHz and 132 MHz.

Two frequencies, 121.5 MHz and 243.0 MHz, are distress and emergency frequencies for use by units of the services of nations equipped to operate in the VHF/UHF band. These frequencies are used only to provide a communications channel between airborne and ground stations, or between surface craft experiencing an actual emergency or distress condition. Other aircraft or surface units in the area can utilize these frequencies in taking immediate action to alleviate or avert the distress or emergency condition; however, these frequencies are not intended for communications incident to a coordinated search and rescue operation.

The first transmission by an aircraft is on the air/ground frequency in use. If the aircraft is unable to establish communications on this frequency, it should broadcast the distress or urgency call on the aeronautical emergency frequency or on any other frequency in an effort to establish contact. However, prior to changing frequency, and if time permits, the aircraft should transmit an appropriate phrase or "Q signal" indicating the frequency to which it intends to change.

A number of communication channels are required to execute the various phases of search and rescue operations and to communicate with aircraft in distress. These channels are listed as follows:

1. Control channel for the operation of search aircraft.
2. Control channel for the operation of search surface craft (including submarines).

NOTE: The frequencies for channels 1 and 2 above are assigned by the local Theater Commander or the local agency responsible for the assignment of frequencies.

3. Communication between survival craft and search aircraft and surface vessels (including submarines). For communication between the survival craft or ground survivors of an accident and ground search parties, search aircraft, search vessels and ground or air monitoring stations, assigned frequencies are 500 kHz, 2182 kHz, and 8364 kHz, 121.5 MHz, and 243.0 MHz.

4. Intercommunication channels between search aircraft and surface vessels (including submarines) are assigned the frequencies 3023.5 kHz, 5680 kHz, 121.6 MHz, 123.1 MHz, 138.78 MHz and 282.8 MHz. The use of 121.5 MHz is also authorized if necessary, but this frequency should be avoided, if at all possible, for search coordinating purposes.

The 123.1 MHz channel is intended for use inside the NATO European area, the 121.6 MHz channel for use in the United States and Canada, and the 138.786 MHz channel for use outside these areas.

DISTRESS PROCEDURES

Distress Signals

In radiotelegraphy, the distress signal consists of the letters SOS (di di dit dah dah dah di di dit) transmitted as a single signal ($\overline{\text{SOS}}$) in which the dashes must be emphasized so as to be clearly distinguishable from the dots.

In radiotelephony the distress signal consists of the word "MAYDAY," which is derived from the French expression "m'aider." These distress signals indicate that the ship, aircraft, or other vehicle sending the distress signal is threatened by grave or imminent danger and requests immediate assistance.

Alarm Signal

When the international distress frequency of 500 kHz is used, the distress call should, if practicable, be preceded by the alarm signal (twelve 4-second dashes, with intervals of 1 second between dashes) using A2 or B emission. If circumstances permit, the transmission of the full distress call should be separated from the end of the alarm signal by an interval of 2 minutes. The alarm signal should always be followed immediately by the distress signal, $\overline{\text{SOS}}$, sent three times, in order to operate automatic apparatus which may depend on the distress signal for activation.

Distress Call

The distress call and message are sent only on the authority of the person in command of the ship, aircraft, or other vehicle carrying the mobile station. The distress call has absolute priority over other transmissions. All stations which receive it must immediately cease any transmission capable of interfering with the distress traffic and must listen on the frequency used for the distress call. This call is not addressed to a particular station, and acknowledgement of receipt is not to be given before the distress message (see below) is sent.

The distress call transmitted by radiotelegraphy consists of:

1. The distress signal, transmitted three times.
2. The prosign DE.

3. The call sign of the mobile station in distress, sent three times.

When the distress call is sent by radiotelephony it consists of:

1. The distress word MAYDAY, spoken three times.
2. The proword THIS IS.
3. The identification of the mobile station in distress, spoken three times.

Distress Message

The distress call must be followed as soon as possible by the distress message. As a general rule, a ship signals its position in latitude and longitude and when practicable, the true bearing and distance in nautical miles from a known geographical point may be given. An aircraft in flight should, if time permits include in its distress message the following information:

1. Estimated position and time of the estimate.
2. True heading and indicated airspeed.
3. Altitude.
4. Type of aircraft.
5. Nature of distress.
6. Intention of person in command (such as forced alighting on the sea or crash landing).

After transmission of its distress message, the mobile station transmits two dashes of approximately 10 seconds duration each, followed by its call sign, to permit direction-finding stations to determine its position.

The distress message must be repeated at intervals especially during "periods of silence," as follows: For 3 minutes, twice each hour, beginning at 15 and 45 minutes past the hour on 500 kHz and on the hour and at 30 minutes past the hour on 2182 kHz in certain designated regions. ("Periods of silence" are defined as periods of time during which all transmissions, except those of an emergency nature, are prohibited. All stations are required to maintain a listening watch on international distress frequencies during these periods.) The intervals used with other repetitions must be long enough to allow time for stations preparing to reply to operate their transmitters.

Immediately before a crash landing or a forced landing (on land or sea) of an aircraft, as well as before total abandonment of a ship or an aircraft, the radio apparatus should be set for continuous emission.

Distress Action

A mobile station which learns that another mobile station is in distress may transmit a distress message if the station in distress is not itself in position to transmit it or if the person in command of the ship, aircraft, or other vehicle, carrying the station which intervenes, believes that further help is necessary.

Mobile stations receiving a distress message which, beyond any possible doubt, is from a mobile station in their vicinity, must immediately acknowledge receipt (unless under radio silence). If the station in distress is not in their vicinity, they must allow a short interval of time before acknowledgement in order to permit stations nearer to acknowledge without interference.

Every mobile station that acknowledges receipt of the distress message and is in position to render assistance, must, on the order of the person in command, transmit the following information as soon as possible; its identification, its position, and the speed at which it is proceeding to the station in distress. Before sending this message, however, the station must insure that it will not interfere with the emissions of other stations better situated to render immediate assistance to the station in distress.

Any mobile station which is not in position to render assistance, and which has heard a distress message that has not been immediately acknowledged, must take all possible steps (unless under radio silence) to attract the attention of other mobile stations which are in a position to render assistance.

Distress Traffic

Distress traffic comprises all messages relative to the immediate assistance required by the mobile station in distress. In distress traffic, the distress signal must be sent before the call and at the beginning of the preamble of any message.

The control of distress traffic is the responsibility of the mobile station in distress, or the mobile station which has sent the distress call.

These stations may, however, delegate the control of the distress traffic to another station.

The station in distress, or any mobile station near the distress station, may request silence from any or all stations which interfere with the distress traffic. It addresses these instructions to all stations or to a particular station only, depending on the circumstances.

When distress traffic has ceased or when silence is no longer necessary, a station which has controlled such traffic transmits on the distress frequency (and, if necessary, the frequency used for distress traffic) a message addressed to all stations indicating that the distress traffic has ceased.

URGENCY SIGNAL

The urgency signal indicates that the calling station has a very urgent message to transmit concerning the safety of a ship, aircraft, or other vessel, or of some person aboard or within sight. It has priority over all other communications, except distress. When the urgency signal is sent from a mobile station, it must, as a general rule, be addressed to a specific station and may be transmitted only on the authority of the person in command.

In radiotelegraphy, the urgency signal consists of three transmissions of the letter group XXX; in radiotelephony, it consists of three transmissions of the word PAN.

When an urgency signal is sent and followed by a message intended for all stations and calling for action by all stations, the station responsible for its transmission must cancel the signal as soon as it knows that the action is no longer necessary. This message of cancellation must be addressed to all stations.

SAFETY SIGNAL

The safety signal indicates that the station is about to transmit a message concerning safety of navigation or giving important meteorological warnings. The safety signal and the message which follows are sent on the distress frequency. With the exception of messages transmitted at fixed times, the safety signal, when used in the maritime mobile service, must be transmitted toward the end of the first available period of silence.

In radiotelegraphy, the safety signal consists of three transmissions of the letter group TTT; in radiotelephony, it consists of the word "SECURITE" (say-cur-i-tay) spoken three times.

The following type messages should be transmitted without delay and must be repeated at the end of the first period of silence:

1. Meteorological warnings.
2. Presence of tropical cyclones.
3. Presence of dangerous ice, wrecks, or other imminent danger to maritime navigation.

PRINCIPLES OF SINGLE SIDEBAND

Single sideband is not a new method of radio communication. It was first conceived in 1915, and has been in use since 1927. The decided advantages offered by SSB (single sideband) make it desirable to develop this method of communication with the possibility that it may eventually replace the DSB (double sideband) in present use.

Production of SSB units was delayed principally because of design obstacles affecting the high degree of stability required in both the transmitter and receiver units. Modern techniques of manufacture have perfected oscillators and filter circuits with sufficient stability and accuracy to make SSB feasible. In the relatively short period of time during which SSB has been in use in naval communications systems, it has produced highly satisfactory results.

The purpose of this discussion is to explain how SSB signals are generated, transmitted, and received, and also present the advantages of SSB over DSB.

To aid in understanding SSB, this discussion presents a review of amplitude modulation and shows a comparison between SSB and present day DSB operation. SSB is amplitude modulation with one sideband and the carrier removed. A more complete discussion of modulation is covered in Basic Electronics, NavPers 10087-B.

There are several methods of obtaining SSB or "semi-SSB" operation. Television, for example, employs a method of transmission whereby most, but not all, of one sideband is suppressed. In some installations the carrier is greatly, but not entirely suppressed. The greatly suppressed carrier is called a "pilot carrier." The pilot carrier is used in the receiver for reference and automatic control. True SSB has the carrier and one sideband entirely suppressed, with only the remaining sideband to be transmitted. Personnel requiring more detailed information on single sideband communications principles than that contained in this manual may refer to Fundamentals of Single Side Band, NavShips 93271.

AMPLITUDE MODULATION

Without modulation, the output of a transmitter is radio energy that has a frequency corresponding to the station's transmitting frequency. This is usually referred to as an unmodulated carrier. The unmodulated carrier is a continuous wave (CW) signal and occupies essentially no bandwidth in the frequency spectrum. Any single radiofrequency (RF) signal can be represented by an infinitely thin vertical line on a plot of amplitude versus frequency.

If a radio wave is to convey voice intelligence, some feature of the wave must be varied in accordance with the voice intelligence to be transmitted. Amplitude modulation consists of varying the amplitude of radiofrequency waves at an audio rate. Amplitude modulation may be defined as the variation of the strength of the RF output of a transmitter at an audiofrequency (AF). In other words, the RF energy has to increase and decrease in power, according to the audiofrequencies. If the audiofrequency is high, the radiofrequency must vary in amplitude more rapidly than if the audiofrequency is low. At the receiver, if the audio note is loud in volume, the radiofrequency energy must be increasing and decreasing by a larger percentage than if the audio note were soft. Thus, the RF variation introduced by the modulation process must correspond in every respect with the AF variations.

High Level

High level plate modulation is so named because the audio signal is injected in the plate circuit of the final RF power amplifier. The plate circuit of the triode class C power amplifier, V1 of figure 16-1, is tuned to a resonant frequency of 1 megahertz which is the transmitter carrier frequency. The plate current is 100 ma and the plate voltage supply is 1,000 v. The grid input driving voltage is produced by an RF oscillator and a buffer amplifier (used to isolate the oscillator from the power stage).

An audio signal of approximately 1,000 volts (peak) having a sine waveform and a frequency of 1,000 hertz is produced by the AF section and

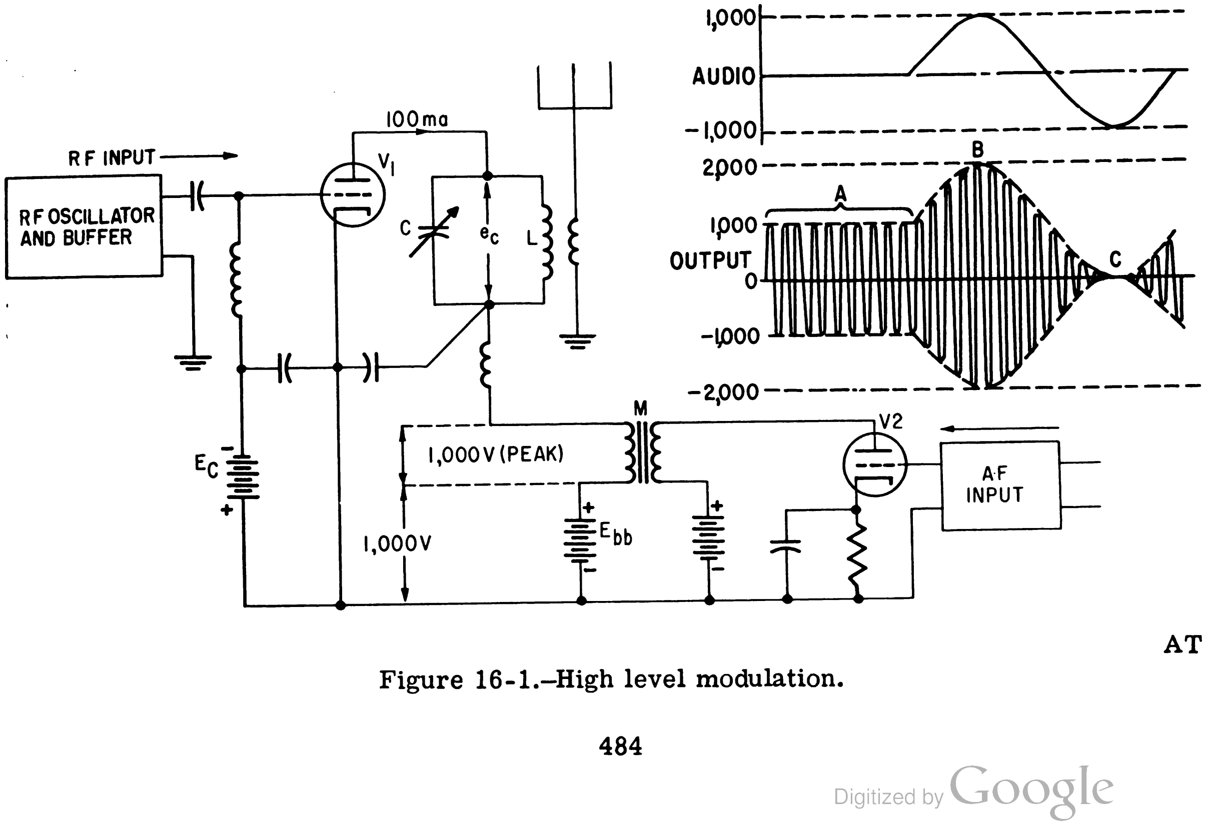

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Figure 16-1.–High level modulation.

appears as an output of the modulation transformer M. This audio output voltage is in series with the RF tank circuit, LC, and the plate power supply of B+ voltage Ebb.

Before an audio-modulation signal is introduced, the RF signal applied to the grid of V1 causes the triode to conduct periodically. During each conducting period, capacitor C charges. When the grid swings below cutoff, the triode stops conducting and the capacitor discharges through the coil.

The exchange of energy between the coil and capacitor accounts for the RF voltage developed across the tank. In this example, the voltage across the tank capacitor C which receives its charge from the 1,000-volt B+ supply is 1,000 volts neglecting losses.

Plate voltage varies above and below 1,000 volts as the capacitor varies between +1,000 and -1,000 volts. The value of the plate voltage is above that of the B+ supply during the part of the cycle when the grid voltage is below cutoff and the triode is not conducting. Plate voltage is below the B+ supply voltage during the time the grid is above cutoff and the triode is conducting. The output of the transmitter is an unmodulated carrier corresponding to the A portion of the output waveform shown in figure 16-1.

Now, assume that the AF (1 kHz) sinusoidal voltage is introduced at M in series with the RF tank and the B+ supply. The frequency of the RF voltage developed across the plate tank is 1,000 times the audiofrequency. Thus the time for one complete audio cycle is long enough to include 1,000 cycles of RF energy in the tank circuit, LC. Consider that portion of the AF cycle in which the voltage is gradually rising according to the sine wave variation so that the polarity aids the voltage of the B+ supply. For 250 cycles of radiofrequency (one-quarter of one AF cycle), the total voltage available for charging capacitor C in the plate tank circuit is increasing from 1,000 volts to a maximum of 2,000 volts. Assume that the capacitor charges to 2,000 volts. The plate voltage at the end of the 250 RF cycles is a maximum of 2,000 plus 2,000 or 4,000 volts. Thus with 100 percent modulation, the value of the peak-to-peak voltage across capacitor C has approximately double the peak-to-peak value it would have without modulation, or four times the B+ supply voltage as shown at point B.

The tank voltage starts to decrease between the 250th RF cycle and the 500th RF cycle, as the AF voltage falls from a maximum of 1,000 volts to zero volts during this period. From the 500th to the 750th RF cycle, the polarity of the AF voltage is reversed and reaches a maximum negative value at the 750th RF cycle, and the tank capacitor charges up to the difference voltage between the 1,000-volt B+ supply and the instantaneous AF value. At the instant the AF voltage is maximum negative (-1,000 volts at the 750th RF cycle), the tank capacitor is not charging at all, the tank voltage is zero, and the RF output energy is zero (point C). The AF voltage starts to rise from maximum negative to zero and the opposition that it offers to the plate supply voltage is reduced. The plate tank capacitor starts charging again, the RF tank current again gradually increases, and the output voltage increases.

The transmitting antenna is coupled to the tank, and the instantaneous antenna current increases and decreases in accordance with the tank current variation. The signal transmitted is 1 MHz modulated at 1 kHz.

Percentage of Modulation

The degree of modulation is expressed by the percentage of the peak-to-peak voltage of the audio to the plate B+ voltage. The effect of a modulated wave as measured by receiver response is proportional to the degree or percentage of modulation.

The percentage of variation of the total voltage of the final RF amplifier stage in high-level plate modulation depends upon the ratio of AF to unmodulated RF plate voltage. For example, if the plate voltage of the RF amplifier is 1,000 volts, and the AF voltage is 1,000 volts, the two voltages add (when they are acting in the same direction) to give 2,000 volts. They subtract (when they are acting in opposite directions) to give zero volts. The modulated plate voltage of the RF amplifier varies between zero and 2,000 volts at the audio rate. Since the variation is equal to the RF voltage variation of 2,000 volts (peak-to-peak) the transmitter signal is said to be modulated 100 percent.

It is important that the transmitted RF energy be kept as close to 100 percent modulation as possible because the output of a detector in a radio receiver varies with the amplitude of the AF component of the received signal. This is why a comparatively low-power station, well modulated, will often produce a stronger signal at a given point than a much higher powered but poorly modulated transmitter located at the same distance from the receiver. The useful limit for the percentage of modulation is 100 percent; this is obtained when the modulating voltage is equal to the plate supply voltage of the modulation amplifier. Under this condition the plate voltage of the amplifier is alternately zero and double the supply voltage (peak values). If the modulating voltage is greater than the supply voltage, over modulation can result; this condition is normally avoided since overmodulation causes severe distortion of the signal.

SIDEBANDS

The circuit of figure 16-1 may be regarded as being composed of two sources of signal voltage and a common load in series. One source is the RF generator, the other is the AF generator, and the load is the resonant tank circuit coupled to the antenna.

When two frequencies are introduced into a circuit having a common nonlinear load impedance (the class C amplifier), these two frequencies combine to produce two additional frequencies. These additional frequencies are called sidebands or sideband frequencies; they are the sum and difference of the original frequencies. However, this is not the complete picture. The nonlinear device will heterodyne or "beat" to produce a theoretically infinite number of frequencies in the output. These exist at the plate of V1 in figure 16-1.

The frequencies fall into four groups:

1. Frequencies identical with those introduced. The amplitude of the current of each frequency in this group is proportional to the amplitude of the voltage of the same frequency in the input wave.
2. Frequencies which are twice the frequency of each component in the input wave—(second harmonics). Harmonics other than the second are produced, but they are very weak and easily dispensed with.
3. Frequencies which are equal to the sum of each frequency in the input with every other frequency in the input; in this case, carrier frequency plus modulating frequency, or upper sideband frequency.
4. Frequencies which are equal to the difference of each frequency in the input from every other frequency in the input; in this case, carrier frequency minus modulating frequency, or lower sideband frequency.

In this example of the principle of modulation, the two frequencies, 1,000,000 hertz (RF) and 1,000 hertz (audio) are impressed on the nonlinear impedance. The following distortion frequencies will also exist: 2,000,000 hertz, 999,000 hertz, 1,001,000 hertz, and 2,000 hertz.

When the carrier plus its upper and lower sidebands are transmitted through a tank circuit resonant at the carrier frequency, each component of a pair of sideband frequencies is shifted in phase. One is advanced and the other retarded by equal amounts as shown in figure 16-2. The curves show how the carrier and sidebands combine algebraically to produce an amplitude-modulated wave with 100 percent modulation by a steady tone.

Figure 16-3 illustrates that the only frequencies (contained in the total output) that fall within the range of the resonance curve are the 1000 kHz, the 999 kHz, and the 1001 kHz. The transmitter final amplifier plate resonant circuit is tuned to the carrier frequency and it attenuates all frequencies present at the plate except the carrier and its upper and lower sideband.

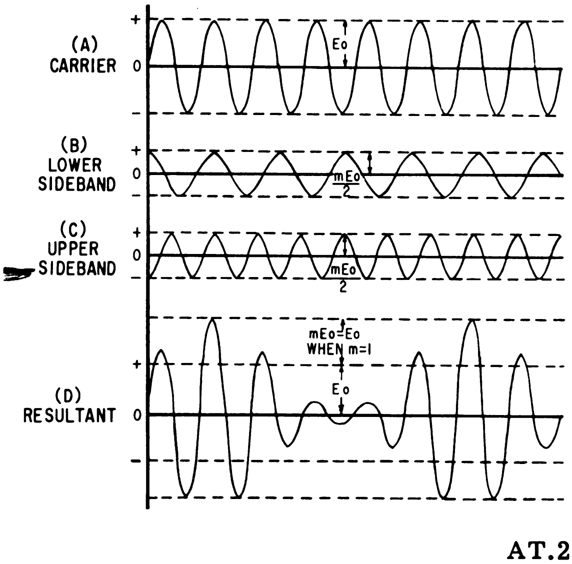

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Figure 16-2.—Modulation waveforms.

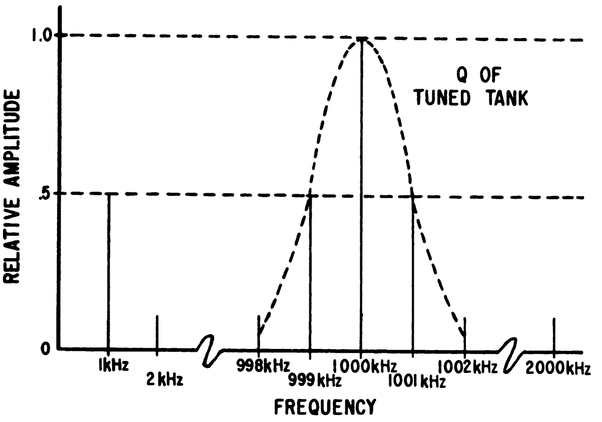

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Figure 16-3.—Selectivity curve.

In actual practice (for communication uses) the modulating wave is usually a complex wave instead of a simple sinusoidal one. In the case of speech or music, the modulating wave may be a wide band of frequencies. For example, if the modulating wave should include frequencies throughout the range of 100 hertz to 5,000 hertz and the carrier is still 1000 kHz (1,000,000 hertz), then two sidebands would be produced. The upper sideband would be from 1,000,100 hertz to 1,005,000 hertz, and the lower one would be in the range of 995,000 hertz to 999,900 hertz. For each component of the original complex audio input band there is a corresponding component in both the upper and lower sidebands.

Since the purpose of this discussion is to emphasize the sideband characteristics of RF waves, as related to communication, it is convenient to use a sideband label for amplitude modulation. This type of modulation can be called double sideband (DSB), to distinguish it from SSB. Double sideband is a better term because, instead of transmitting only one frequency, the antenna is actually radiating two sidebands plus the carrier frequency. These frequencies are close together and within the bandwidth of the RF amplifier resonant circuit.

Double Sideband Power Requirements

The amount of power required to modulate a DSB transmitter depends on the percentage and type of modulation. To modulate a carrier 100 percent with a pure sine wave of audiofrequency requires an audio power source equal to one-half the RF carrier power. With 100 percent modulation, the amplitude of each sideband is one-half the amplitude of the carrier. Power is proportional to the square of the current; thus each sideband contains one-half the current and one-fourth the power. This is shown in figure 16-4 which depicts the carrier and the sideband waveforms which are the resultant of modulating a 1000 kHz carrier with a 1 kHz tone, assuming 100 percent modulation.

As shown in figure 16-4 if power output is to remain constant, it would be necessary to increase the input power by 50 percent when shifting from unmodulated to tone modulated operation, assuming 100 percent modulation. In voice modulation the greatest portion of the AF components will not modulate the carrier 100 percent. Thus, the power requirements are considerably less than that required for tone modulation.

An amplifier in a modulation circuit must handle extremely high peak currents; up to four times the power it dissipates during the periods when no modulation is applied.

Demodulation

New frequencies are created in the process of demodulation. For example, if a 1 kHz signal modulates a 1000 kHz carrier, sidebands of 1001 kHz and 999 kHz are created as shown in figure 16-4. Also, if the 1000 kHz signal were made to modulate the 1001 kHz sideband, an upper frequency of 2001 kHz and a lower frequency of 1 kHz would be created. Provided that propagation does not cause any shift in their phases relative to each other, the 1 kHz signals are in phase. Note that 1 kHz is the original modulating frequency. This is the mechanism of the demodulation action. A carrier frequency and received sideband frequencies modulate one another and produce new frequencies, among which is the desired audiofrequency.

Sum and difference frequencies are important in the modulation and demodulation of DSB waves. To produce sum and difference frequencies, it is necessary to change the shape of the input waves. This is done by impressing the waves on a nonlinear device. DSB modulators and demodulators are usually nonlinear devices, such as class C amplifiers and diodes.

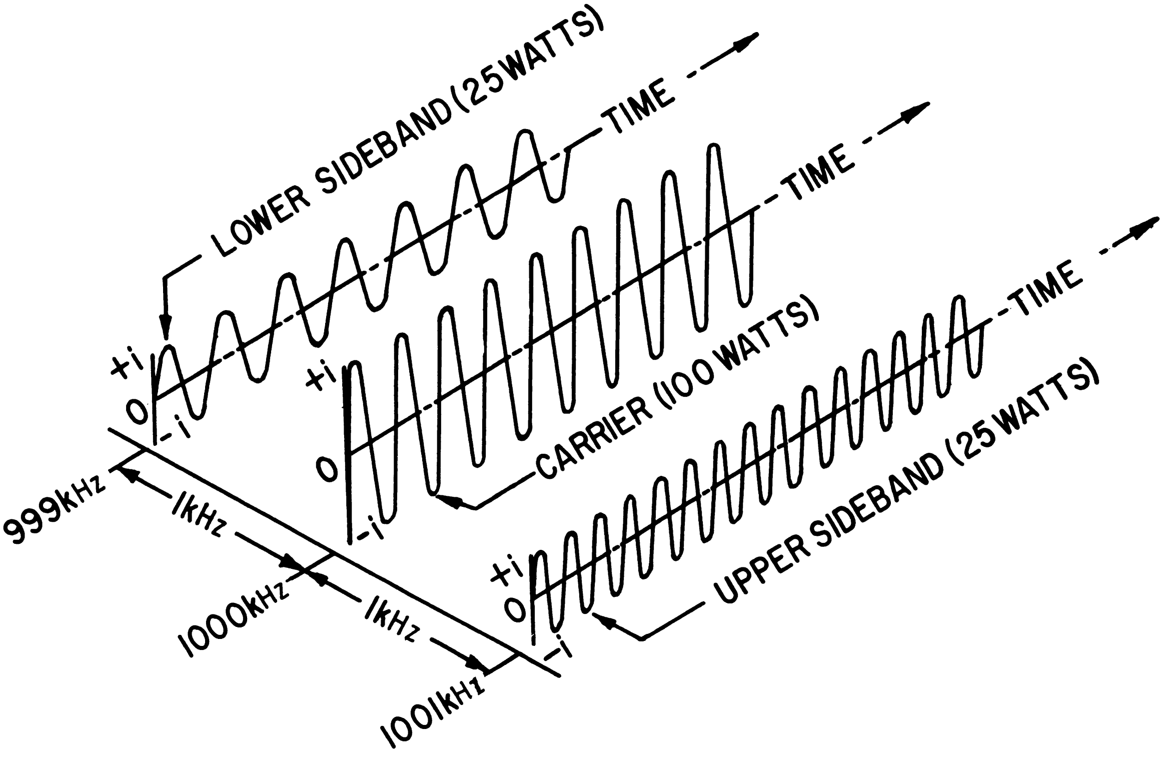

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Figure 16-4.—Carrier and sideband power.

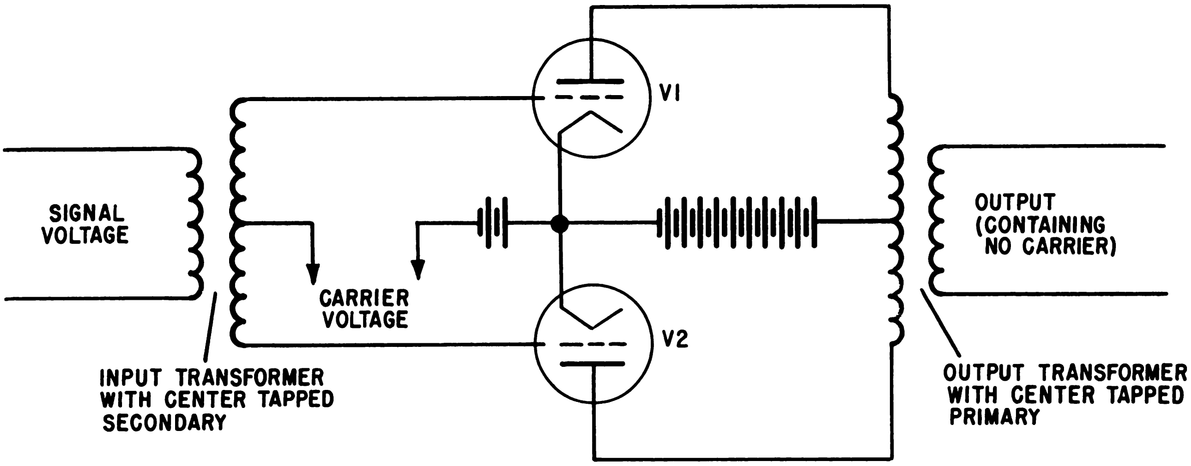
It has been pointed out that in DSB systems there exists two sidebands that are demodulated in the receiver to produce a single audio signal that carries the voice intelligence heard in a speaker or headset. In the process of demodulation a signal equal to the original audio signal is produced from two sources; one by each sideband beating with a signal of the same frequency as the carrier frequency. Since either sideband contains all the intelligence, one sideband may be removed by a filter without interfering with the overall transmission of the original audio signal. The total RF transmission band covered would be cut in half if one sideband were eliminated, with the result that more channels could be operated within a given range of frequencies. In addition, distortion caused by propagation effects would be eliminated.

The only purpose of the carrier is to serve in the demodulation of the incoming signal. Since the carrier is used in the demodulation process, it is possible to eliminate the carrier at the transmitter and reintroduce it at the receiver. This carrier elimination is the major principle of SSB operation, and is discussed in subsequent paragraphs.

CARRIER AND SIDEBAND SUPPRESSION

The carrier may be eliminated or suppressed by some arrangement such as the balanced-modulator circuit shown in figure 16-5.

The carrier voltage is applied to the two modulator tubes in the same phase (push-push) while the modulator signal voltage is applied in opposite phase (push-pull) to the two grids by means of the center-tapped transformer. The outputs in the plate circuits of the two tubes are combined through a transformer with a center-tapped primary in such a way that voltages applied to the two grids in push-push cancel each other in the output (plate circuit); whereas voltages applied to the two grids 180° out of phase (push-pull) are added in the output. Thus the carrier voltage, which is applied to the two tubes


VI
SIGNAL VOLTAGE
CARRIER VOLTAGE
OUTPUT (CONTAINING NO CARRIER)
V2
INPUT TRANSFORMER WITH CENTER TAPPED SECONDARY
OUTPUT TRANSFORMER WITH CENTER TAPPED PRIMARY

AT.282

Figure 16-5.–Balanced modulator.

in push-push, does not appear in the secondary of the output transformer. On the other hand, the sideband components (audio), which are applied in push-pull, are added in the output. The result is an output that is a modulated wave from which the carrier component has been removed.

The output from the balanced modulator tubes contains three of the four groups of frequencies already mentioned in the discussion of nonlinear devices. These groups are as follows:

1. Frequencies identical with the components of the signal voltage in the input, but none at the frequency of the carrier.
2. Frequencies equal to the sum of the carrier frequency and each component in the signal.
3. Frequencies equal to the difference between the carrier frequency and each component in the signal.

Now that the carrier has been eliminated, all that remains is to eliminate one of the sidebands. This can be accomplished by either the filter method or the phasing method. These methods are explained following a discussion of the various types of filters.

Both SSB transmitters and SSB receivers require extremely selective bandpass filters in the region of 100 kHz to 500.

In receivers, a high order of adjacent channel rejection is required if channels are to be closely spaced for conservation of spectrum space. In SSB transmitters, the signal bandwidth must be limited sharply in order to pass the desired sideband and reject the other sideband. The filter used, therefore, must have very steep skirt characteristic (fast cutoff) and a flat bandpass characteristic in order to pass all frequencies in the band equally well. These filter requirements are met by crystal filters, LC filters, and mechanical filters.

Suppression Devices

CRYSTAL FILTERS.–Until recently, crystal filters used in commercial SSB equipments were in the 100 kHz range. Such filters have excellent selectivity and stability characteristics, but their large size makes them subject to shock or vibration deterioration. Also, their cost is quite high.

Crystal filters with extended frequency range, and smaller in size, are being developed. These filters are more acceptable for use in SSB equipment.

LC FILTERS.–LC filters have been used at IF frequencies in the region of 20 kHz. However, generation of the SSB signal in this low frequency range requires an additional mixing stage to obtain a transmitting frequency in the high-frequency range. For this reason, LC filters are not widely used in SSB equipment.

MECHANICAL FILTERS.–Recent advancements in the development of mechanical filters have led to their acceptance in SSB equipment.

Mechanical filters have excellent rejection characteristics, are extremely rugged, and are small enough to be compatible with miniaturization of equipment. Another advantage of the mechanical filter is a Q in the order of 10,000, which is about 100 times the Q obtainable with electrical elements.

Although the commercial use of mechanical filters is relatively new, their basic principles are well established.

The mechanical filter is a mechanically resonant device that receives electrical energy, converts it into mechanical vibration, then converts the mechanical energy back into electrical energy at the output. The mechanical filter consists basically of four elements:

1. An input transducer that converts the electrical input into mechanical oscillations.
2. Metal disks that are manufactured to be mechanically resonant at a certain frequency.
3. Coupling rods that couple the metal disks.
4. An output transducer that converts the mechanical oscillations back into electrical oscillations.

Figure 16-6 shows the elements of the mechanical filter.

The transducer may be either a magnetostrictive device or an electrostrictive device.

The magnetostrictive transducer utilizes the principle that certain materials can be made to elongate or shorten when in the presence of a magnetic field. Therefore, if an electrical signal is sent through a coil whose core is made of a magnetostrictive material, the electrical oscillation will be converted into mechanical oscillation. The mechanical oscillation can then be used to drive the mechanical elements of the filter, which are the disks.

The electrostrictive transducer utilizes the principle that certain materials, such as piezoelectric crystals, will compress when subjected to an electric current or voltage.

Both types of transducers have a natural resonant frequency. They are manufactured to be resonant at a specific frequency. Transducers are chosen for a particular application, such as the ability to pass the frequencies of one sideband and reject all other frequencies.

Figure 16-7 (A) is the block diagram of an SSB transmitter that utilizes mechanical filters. Filtering action by the mechanical filter (similar to that shown in fig. 16-6) is accomplished in the following manner. The first bandpass filter will receive only the two sidebands of the modulated signal from the low-frequency modulator. (Elimination of the carrier by the balanced modulator was explained earlier.)

The metal disks of the mechanical filter pass only the frequencies of the desired sideband. Although the transducer driving rod applies the frequencies of both sidebands to the

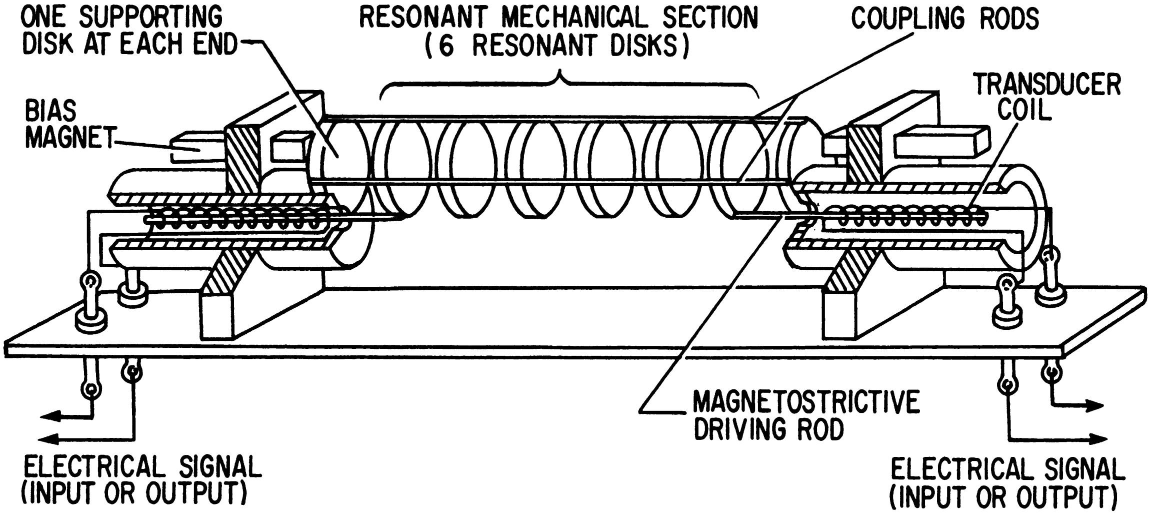

ONE SUPPORTING DISK AT EACH END
RESONANT MECHANICAL SECTION (6 RESONANT DISKS)
COUPLING RODS
TRANSDUCER COIL
BIAS MAGNET
MAGNETOSTRICTIVE DRIVING ROD
ELECTRICAL SIGNAL (INPUT OR OUTPUT)
ELECTRICAL SIGNAL (INPUT OR OUTPUT)

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Figure 16-6.—Mechanical filter.

first disk, the vibration of the disk will be greater at its resonant frequency than at the unwanted sideband frequency.

Mechanical vibration of the first disk is transferred to the second disk. Each time the vibrations progress from one disk to the next there is a smaller percentage of the unwanted sideband frequencies transferred. After six disks have been set in motion, virtually all of the unwanted sideband frequencies have been suppressed. The remaining (desired) sideband frequencies are taken off the transducer coil at

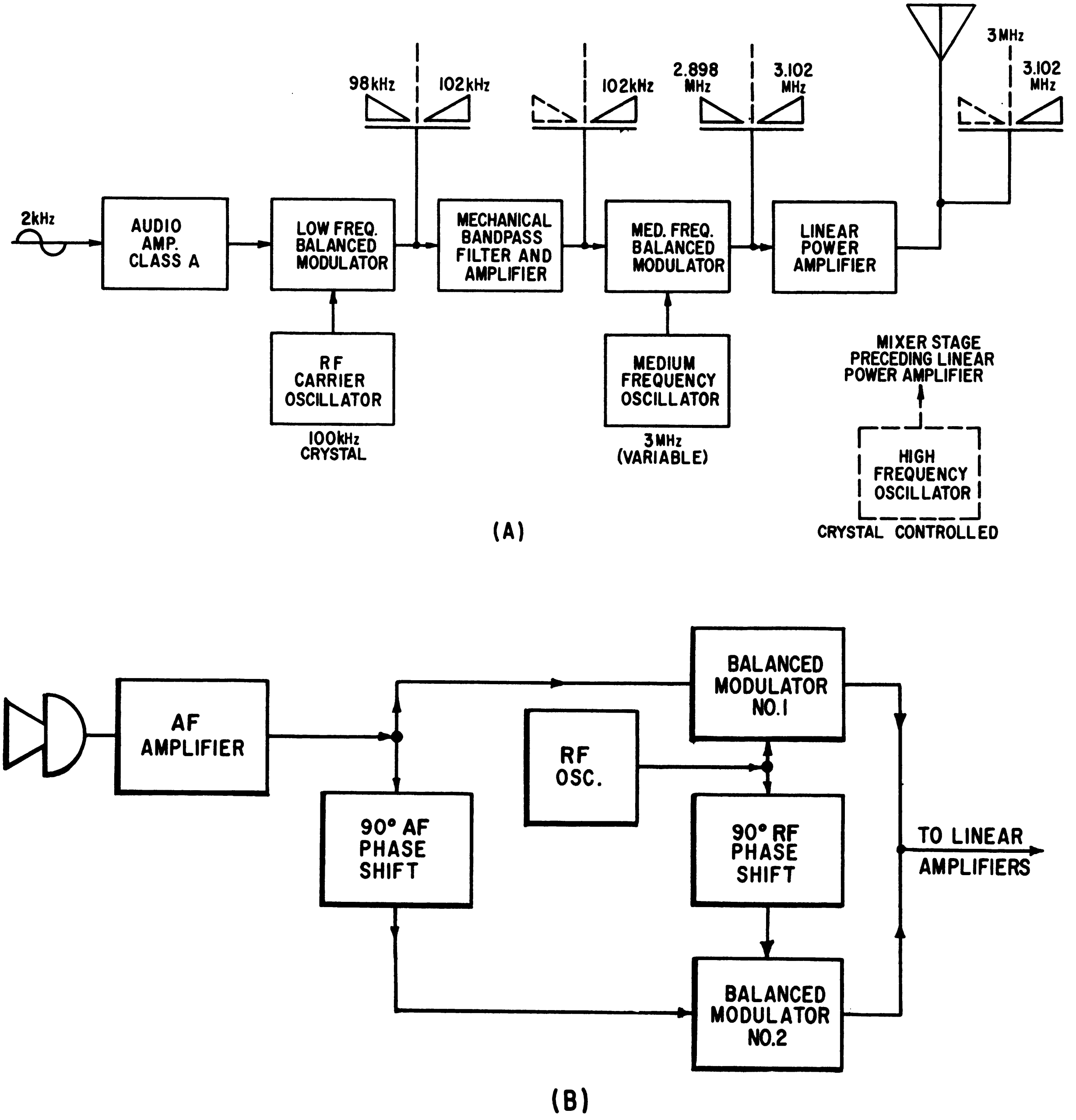

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Figure 16-7.–Two principles used in producing SSB transmission.

the terminal end of the filter. It is interesting to note that either end of the filter may be used as the input, and either end used as the output.

By varying the mechanical coupling between the disks (that is, by making the coupling rods larger or smaller) the bandwidth of the filter is varied. Because the bandwidth varies approximately as the total area of the coupling rods (in magnetostrictive transducers), the bandwidth can be increased by using either larger coupling rods or more coupling rods. Mechanical filters with bandwidths as narrow as 0.5 kHz and as wide as 35 kHz are practical in the 100 kHz to 500 range.

Suppression Methods

The most simple and direct means of accomplishing SSB transmission by the filter method would be to filter out the carrier and one sideband of the conventional DSB system. This is not feasible since, if this system were used with conventional DSB transmitter circuits, filters capable of dissipating large amounts of power would be required in the transmitter output stage. This would result in a waste of power. To avoid this, the balanced modulators and filters are used in the low-power stages of a transmitter. The filter is required to accomplish the following:

1. Pass the desired sideband.
2. Limit the bandwidth of the desired sideband to that required for an intelligible communications circuit.
3. Provide adequate suppression of the undesired sideband.
4. Provide some attenuation of any remaining carrier frequency.

The ideal filter characteristics are shown as a solid line in figure 16-8. The solid line represents the ideal filter curve, which would pass only the upper sideband and reject the carrier and the lower sideband. The dotted line represents the filter curve that usually exists, which may vary depending on the type of filter used. A filter having those characteristics would be used as the first filter in figure 16-7 (A). In actual practice such a filter does not exist. But there are some filters that approach the requirements stated above, such as the electromechanical bandpass filter and the crystal lattice filter.

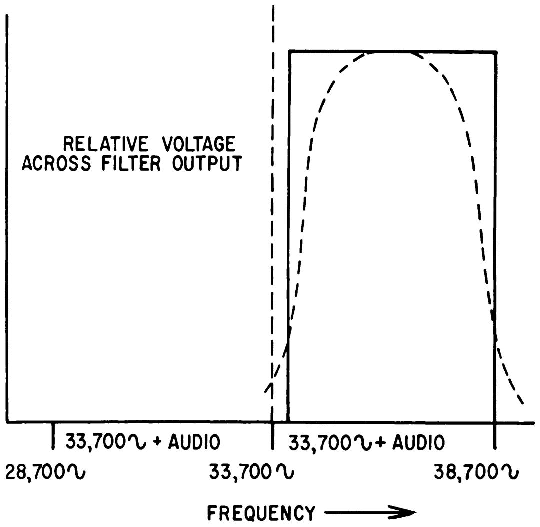

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Figure 16-8.—Filter characteristics.

Refer again to the block diagram in figure 16-7 (A) which is a block diagram showing the use of mechanical filters and a balanced modulator. The frequencies used in the illustration are the result of using a 2,000 hertz single-tone audio signal. In actual practice a complex audio signal would normally be utilized.

The 2 kHz audio signal is amplified and mixed in the balanced modulator with a 100 kHz carrier. Remember, the carrier does not appear in the output of the balanced modulator. When mixed, however, the sum and difference frequencies do appear in the output. The 2 kHz (fundamental) signal is so far from the frequency of the mechanical filter that it can be ignored. The dotted line shows where the carrier has been removed. Removal of the lower sideband is accomplished by the mechanical filter.

Because the remaining sideband is too low in frequency, it must be mixed again with a 3 MHz signal to raise it to the desired transmitter frequency. Again, the balanced modulator removes the two fundamentals and applies the two new sidebands (sum and difference) to the linear power amplifier. The input and output circuits of the linear power amplifier are tuned to reject one sideband and pass the other to the antenna for transmission.

In actual practice a high frequency oscillator, shown in dotted lines in figure 16-7 (A), would be used prior to the power stage. Also, the medium frequency oscillator is variable so that transmitter output frequency can be varied.

The power stage may be two or three power amplifiers. Since the carrier is suppressed in the balanced modulators and one sideband is removed by the filters, all of the transmitted energy is in the single sideband. This is sometimes called "talk power." Since only the talk power is radiated, it follows that when no audio is being applied to the transmitter there is no transmitter output, even though the transmitter is fully activated.

Since only one sideband is required for signal transmission, single sideband transmitters may be used to transmit two messages, one by the lower sideband and the other by the upper sideband. In order to do this, each message modulates the same carrier but in different modulators, as illustrated in figure 16-9. In a transmitter of this type, the outputs of the two modulators usually contain the same carrier (reduced) as well as the different sidebands.

Filter circuits are provided for removing the upper sideband from one modulator output and the lower sideband from the other. The remaining sideband frequencies are then radiated from one antenna along with the reduced or suppressed carrier. Thus, each of the two sidebands conveys a separate message and may be used to provide a separate audio channel. Reception of the two channels requires only one receiver with suitable circuits for separating and demodulating each channel.

Phase cancellation can also be used to eliminate the unwanted sideband. One system uses two balanced modulators connected as shown in figure 16-7 (B). Balanced modulator No. 1 has the carrier and modulating signals directly applied, while in balanced modulator No. 2 both signals are shifted 90° in phase. When the outputs of these two modulators (Nos. 1 and 2) are added, one phase is eliminated or canceled, and the other is reinforced.

SSB AMPLIFICATION

The most desirable combination of characteristics in linear amplifiers combines low distortion with maximum power gain. A linear amplifier is an amplifier having a certain power or voltage gain and an output waveform which exactly resembles the input waveform. Speech amplifiers or modulators are linear

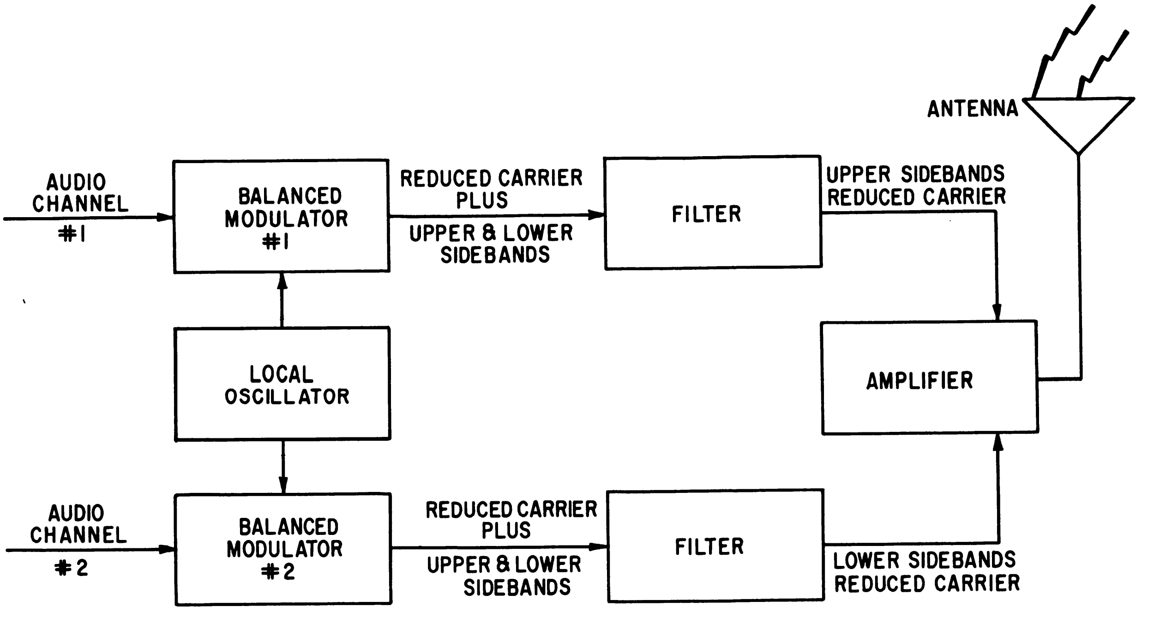

Figure 16-9.–Two-channel SSB system.

amplifiers. The speech amplifiers are linear audio voltage amplifiers while the modulators are linear audio power amplifiers. The only difference between linear audio amplifiers, and SSB amplifiers is the frequency involved—one is audiofrequency and the other radiofrequency. The same operating conditions are used, such as plate voltage, bias, load impedance, and so forth, in both cases. As has already been mentioned, nonlinearity produces distortion and distortion is highly objectionable in SSB because it can produce splattering into adjacent channels. This splattering is easily detected by sensitive receivers.

Class A operation of amplifiers gives a high degree of linearity and they are usually the ones referred to when speaking of linear amplification. But these have low power gain, and thus would result in a considerable power loss in high-power transmitters. Class AB operation is used in amplifiers when higher power gain is needed. High gain is required in SSB amplifiers because the modulated signal is usually generated at low levels (1 watt or less). To raise this level to a kilowatt requires high gain. To obtain high gain with a minimum number of stages and circuits requires the use of high gain tetrodes or pentodes, usually operated class AB. A minimum number of amplification stages is desired because each amplification stage produces distortion. However, negative feedback in RF circuits can be utilized to reduce distortion in the same manner as negative feedback in audio circuits. This is done by applying a sample of the output waveform to the amplifier's input to correct any distortion produced within the amplifier.

SSB RECEPTION

In the reception of SSB, the receiver must have rigid frequency stability because the reception is not as simple as with DSB signals. As previously mentioned, the receiver has the problem of furnishing an artificial carrier, since the SSB signal does not contain a carrier against which the sideband signals can be heterodyned in the receiver to demodulate the sideband and produce useful audio signals. As a rule, the artificial carrier is furnished by a highly stable beat frequency oscillator in the receiver.

It is necessary that the SSB transmitter have the same degree of stability as the receiver. The maximum allowable drift between transmitter frequency and receiver frequency is about 50 hertz for good voice reception. A 50 hertz difference between transmitter and receiver will distort or change the pitch of the person's voice by 50 hertz. Although the intelligence is still there, it does not constitute "good voice reception."

Figure 16-10 is a block diagram showing the essential functions of an SSB receiver.

The receiver employs necessary switch and tuning circuits to receive any signal within its frequency range, and to switch from upper sideband to lower sideband reception.

After the received signal is amplified, it is applied to mixer stages that lower the frequency. This is done in the same manner by which the frequency was raised in the transmitter. The carrier, necessary for heterodyning in the detector, is then inserted. Notice that the carrier generator is controlled by a frequency standard, as is the stabilized master oscillator (SMO), to maintain rigid frequency stability. After detection the original 2 kHz signal is fed to conventional audio amplifier stages.

Many of the units of an SSB receiver are identical with units of the SSB transmitter. The frequency standard, carrier generator, and SMO are identical. The double conversion mixer and amplifier unit of the receiver can be made identical to the double conversion mixer and amplifier unit of the transmitter. Because of this similarity, transceivers can be constructed with much of the circuitry used for both transmitting and receiving. This can be accomplished by merely adding switching arrangements to reverse the direction of signal flow.

SSB ADVANTAGES

In conventional DSB techniques of communication, there is a carrier, an upper sideband, and a lower sideband. The sidebands "beat" with the carrier to produce a single audio signal that carries the voice intelligence that is heard in the speaker or headset. If the upper or lower sideband is shifted in phase due to

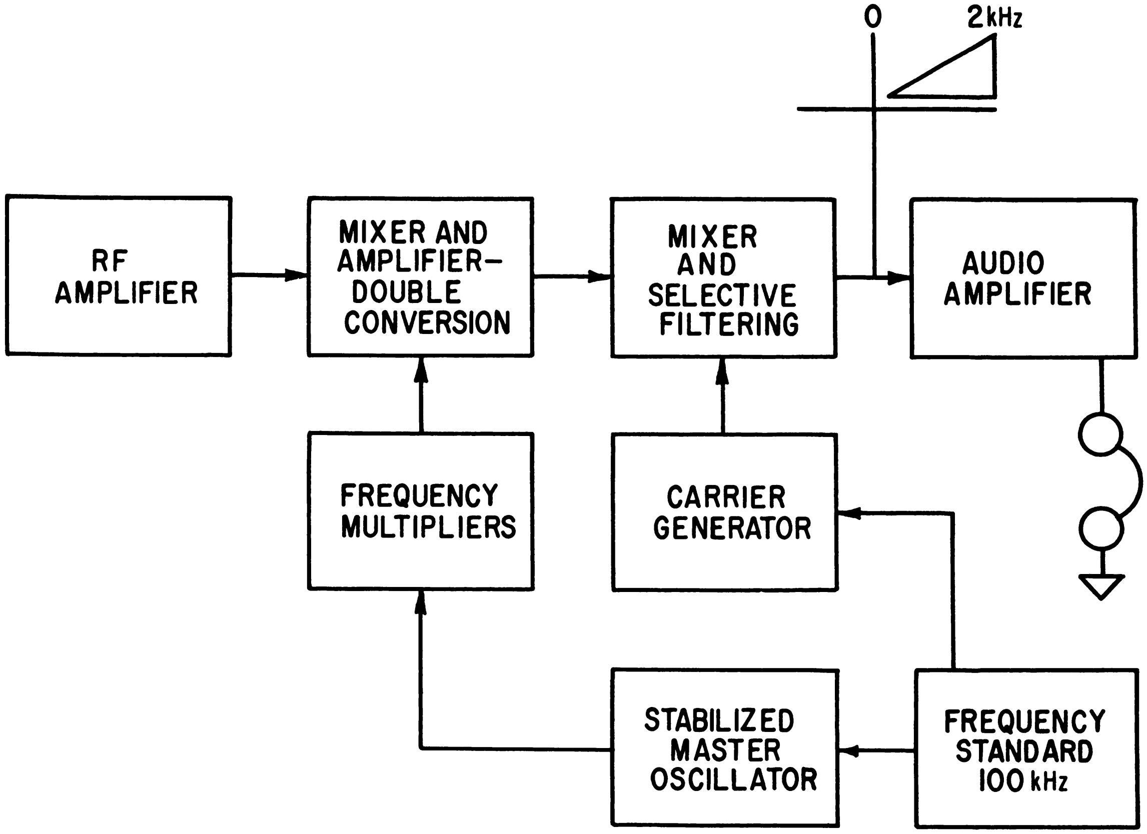
0
2kHz
RF AMPLIFIER
MIXER AND AMPLIFIER– DOUBLE CONVERSION
MIXER AND SELECTIVE FILTERING
AUDIO AMPLIFIER
FREQUENCY MULTIPLIERS
CARRIER GENERATOR
STABILIZED MASTER OSCILLATOR
FREQUENCY STANDARD 100 kHz

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Figure 16-10.—SSB receiving system.

multipath skywave propagation conditions, the signal heard is fuzzy, distorted, and in all probability quite loud. It is not uncommon to receive a report stating "loud but distorted." One sideband may experience a slight phase shift, thereby nearly canceling the other. The distortion produced causes the loss of intelligibility. Fading or slight phase shift of the carrier can also produce similar results. These problems reportedly do not exist in the suppressed-carrier type of SSB, particularly in the frequency range below 14 MHz.

In conventional DSB technique of communication, with 100 percent modulation, approximately (neglecting losses) two-thirds of the transmitter's radiated power is in the carrier, and the remaining one-third is divided equally between the two sidebands. DSB and SSB modulation relationship is illustrated in figure 16-11. An unmodulated carrier of frequency f1 with an average of 1,000 watts is shown in (A) of the figure. Information can be transmitted by keying the carrier on and off, as in CW. The entire 1,000 watts of carrier power is used in transmitting information. In figure 16-11 (B) the same transmitter is shown being modulated 100 percent by a single sinewave tone of frequency f2. The useful information is contained only in the upper sideband frequency (f1 + f2) and lower sideband frequency (f1 - f2) that exist on either side of the carrier frequency.

Notice that the useful power is only 50 percent of that attained by the CW in figure 16-11 (A). For practical voice modulation waveforms, this useful power may not exceed 30 percent of the total power. Figure 16-11 (C) represents a method of transmission known as a twin-channel single-sideband reduced-carrier system. (See fig. 16-9.) The carrier is not completely suppressed, but is reduced approximately 20 db in amplitude, serving as a pilot

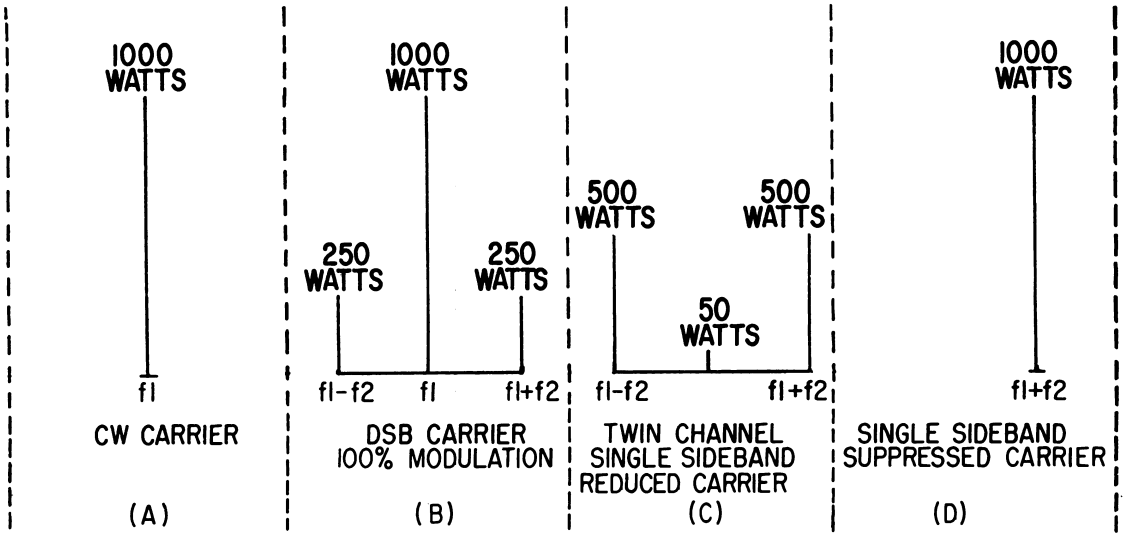

Figure 16-11.–DSB and SSB modulation power relationship.

carrier. This pilot carrier is used as a reference for obtaining a reinserted carrier of correct frequency and phase in the receiver demodulator circuits, and for the AGC (automatic gain control) circuits. Figure 16-11 (D) represents a single-sideband suppressed-carrier system with complete suppression of the lower sideband and carrier. The only energy radiated by this method is modulation energy.

In this method a higher degree of oscillator frequency stability is required for both the transmitter and receiver circuits than for the method using the pilot carrier. Thus, with the suppressed-carrier SSB system, all of the power goes into the single sideband which carries the useful voice intelligence.

Since there are good and poor suppressed-carrier SSB signals as well as good and bad DSB signals, it would not be fair to compare a good DSB signal with a bad suppressed-carrier SSB signal, or vice versa.

In any system of comparison, it is essential that conditions under which the comparison is made be clearly defined. Figure 16-12 illustrates one method of comparison of suppressed-carrier SSB and DSB. The comparisons made here assume coherent detection of sidebands in DSB and also ignore the possible differences that can occur under various propagation and interference conditions. Figure 16-12 compares "talking power" between DSB and SSB. It illustrates that as bandwidth is decreased SSB transmitter requires progressively less power output to obtain the same "talk power" as a DSB transmitter. In this illustration the output of the DSB transmitter is 1,000 watts.

Figure 16-12 (A) illustrates that a 1,000-watt DSB transmitter will "talk" just as loud as a 1,000-watt SSB transmitter if both are received on a wide-band (6 kHz) receiver. Figure 16-12 (B) illustrates that under optimum conditions–that is, DSB received at bandwidth of 6 kHz and SSB received at bandwidth of 3 kHz–the talking power of a 500-watt suppressed carrier SSB transmitter is equal to that of a 1,000-watt DSB transmitter. Figure 16-12 (C) illustrates that if both DSB and suppressed-carrier SSB are received on a narrow bandwidth receiver, then the talking power of the 250-watt SSB transmitter is equal to that of a 1,000-watt DSB transmitter.

It has generally been accepted that, under normal operating conditions with moderate signal-to-noise ratios, the improvement in gain using SSB is between 6 and 9 db over the gain of an equivalent DSB transmitter. The suppressed-carrier SSB transmitter provides 6 db gain and the remaining db gain is derived from

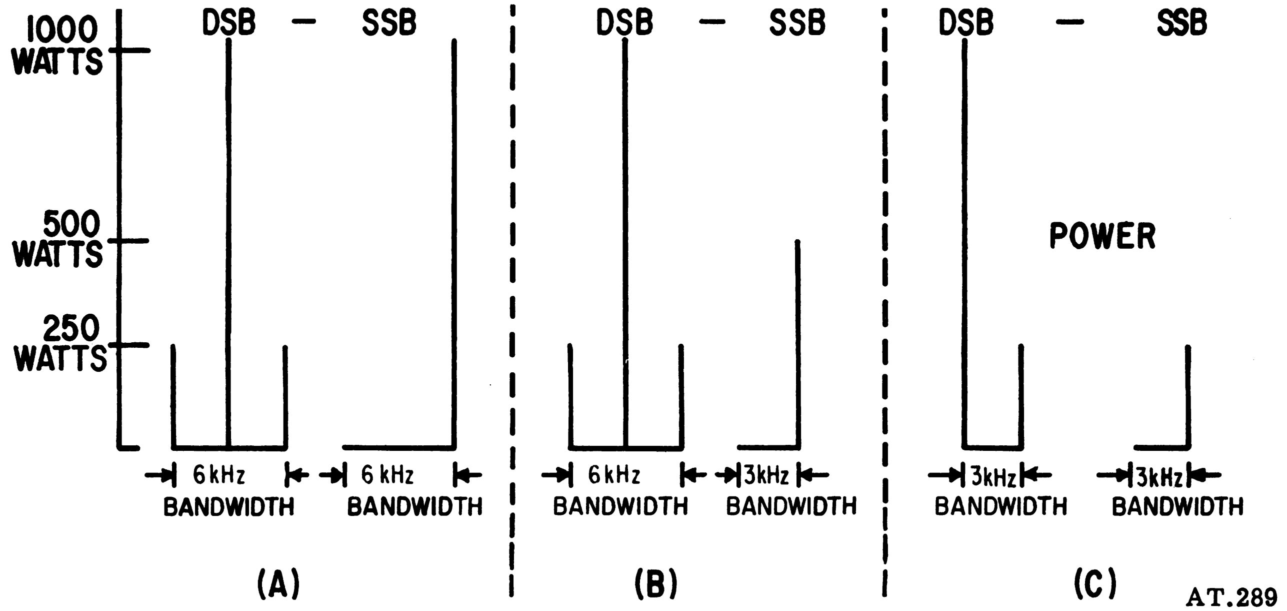

Figure 16-12.–DSB and SSB power comparison.

the narrow-band single-sideband receiver's selectivity. Propagation conditions determine the relative advantages of suppressed-carrier SSB over DSB. As the interference and/or selective fading becomes worse, SSB indicates a greater advantage over DSB.

Another advantage of SSB operation is that interference is reduced. In normal voice DSB communication, the carrier of the transmitter remains on the air until the transmitter is turned off. If a second transmitter transmits while the carrier of the first station is on the air, distortion results. Squeals and howls are caused by the heterodyning of two or more signals being transmitted at the same time. With SSB, as soon as the sender stops speaking into the microphone, "talk power" in the sideband leaves the air even if the transmitter is still on; receiving equipment is not affected by the SSB carrier (reduced carrier when used) alone.

When two SSB stations transmit at the same time, a receiving station can receive through the interfering station in the same way that an individual is able to listen to more than one conversation at the same time.

INTEGRATED COM-NAV-IFF SYSTEMS

The integrated communications, navigation, and identification system was brought about by the advent of the weapons system concept in naval aircraft. This system, called COM-NAV-IFF (CNI) in some installations and INTEGRATED ELECTRONIC CENTRALS (IEC) in others, is the natural result of the expanded electronic functions, restricted space, critical weight factors, and more severe environmental conditions imposed upon the newer high performance naval aircraft.

BASIC CONCEPTS

The integrated units for specific aircraft are designed to best fit into the overall weapon system of the aircraft. The system is designed to combine into one integrated system the functions previously performed by numerous independent electronic equipments. Figure 16-13 is a block diagram of a typical CNI system. Functional names of components are used; rather than AN nomenclature, since this diagram is representative of a general system rather than a specific aircraft configuration.

In most CNI systems the mounting racks serve a dual purpose. They act as shock mounts and in addition serve as a specialized chamber for distributing cooling air to each of the major components. In addition, components which contain high voltage circuits are pressurized to prevent arc-over at high altitude. The units

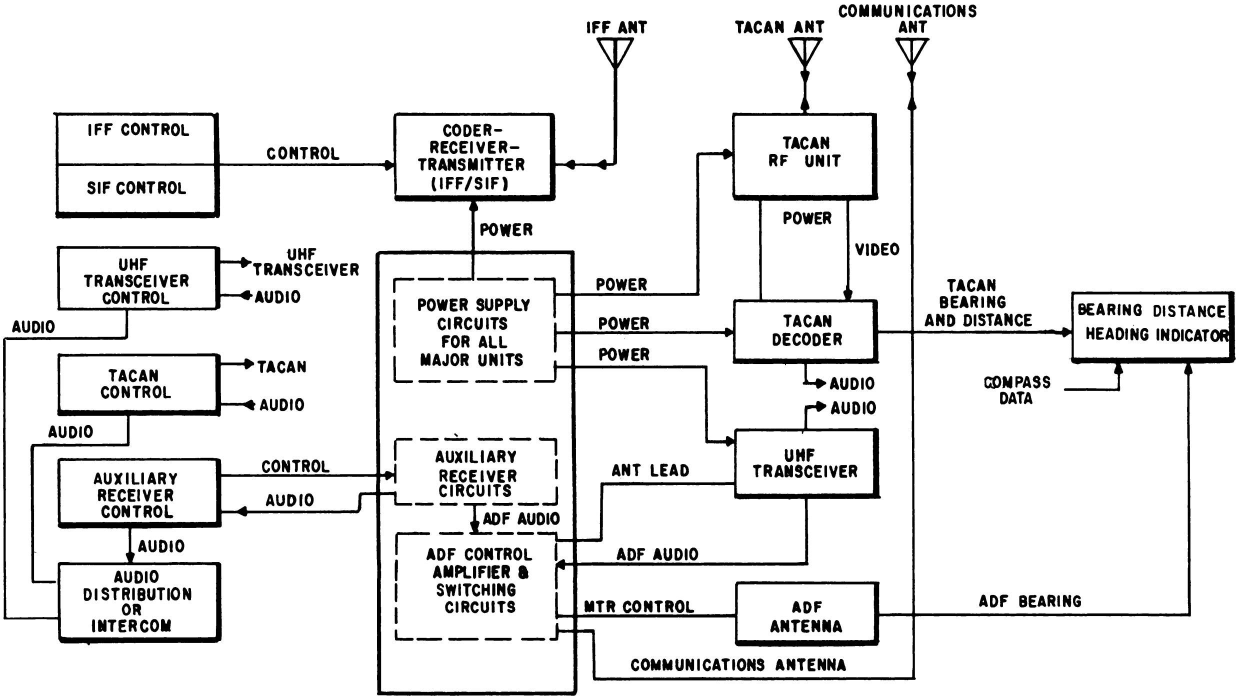

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Figure 16-13.–Typical CNI system.

which do not require pressurization are supplied directly with cooling air.

Communications Function

UHF radio communication facilities are provided by one or more transceiver units, permitting voice transmission and reception on any of 1750 channels in the frequency range of 225.0 MHz to 399.9 MHz. A separate fixed frequency guard channel receiver in the transceiver unit is normally tuned to the emergency frequency of 243.0 MHz. An auxiliary UHF receiver is also normally included in the system. This receiver operates on any one of 20 preset channels in the frequency range of 265.0 MHz to 284.9 MHz, and on an additional guard channel. The auxiliary receiver is employed with the UHF ADF system in order to provide independent UHF direction-finding functions without disrupting the normal communications facilities.

Navigation Function

The navigation function includes both TACAN and ADF. The TACAN facilities are provided by two units, a radio receiver-transmitter and a pulse decoder. The output of the pulse decoder is used to drive indicators which display bearing and distance to the selected TACAN beacon, deviation from a selected course, and TO-FROM information to indicate whether the selected course is to or from the beacon.

The UHF ADF can be operated using two receiver sources, the UHF communications receiver or the auxiliary receiver.

Indentification Function

The identification facilities are provided by a pulse type transponder which automatically radiates replies to interrogations from ground, shipboard, or airborne IFF stations. Either normal (Mark X IFF) or selective indentification feature (SIF) coding of the replies may be utilized. This facility performs the functions provided by both the AN/APX-6B and the AN/APA-89 in older aircraft.

Power Supplies

Power supply modules distribute power from a centralized source to the major units. Special emergency switching features remove power from certain navigation functions to reduce the load on the power source in case of flame out, generator failure, or other emergency. The specific functions which are not available in an emergency will vary from one aircraft to another; information on this subject may be found in the technical manuals for specific aircraft models.

The centralized power supply provides a means of saving weight in an integrated installation. The components utilized in power supplies are often very heavy when compared to other electronic components, therefore, combining the power supplies eliminates numerous heavy components.

F-4B CNI SYSTEM

The CNI system for the F-4B aircraft is the Integrated Electronic Central AN/ASQ-19. It provides UHF communications, TACAN and ADF navigation, radar identification (IFF), instrumentation, and interphone functions. It is packaged in five major units: UHF Communications, unit 1; Navigational RF, unit 2; Navigational Instrumentation, unit 3; IFF/Coder, unit 4; and Auxiliary Receiver/ADF/Power Supply, unit 5. Placement of these units as well as some minor units and associated components is depicted in figure 16-14.

Units 2 through 5 are mounted above and below a common shelf installed aft of the aircraft's nosewheel well. The shelf as a whole is shock-mounted; it provides interunit wiring and connections, and serves as a plenum chamber for refrigerated air. Of these four units, the Navigation RF Unit is the only one in a pressurized case.

UHF Communication Unit

The UHF communication unit (fig. 16-14, unit 1), is located in the aft cockpit; it, too, is pressurized, but has a self-contained blower circulating cockpit air through a heat exchanger. Accessories to the system include fore and aft integrated control boxes, unit 6; fore and aft station intercommunication system, units 7 and 8; ADF antenna, unit 9; and bearing-distance-heading indicator, unit 10.

In general, the modules, though improved for the CNI system, were utilized in previously developed Navy modularized equipment. Radio receiver-transmitter, unit 1, is designed to provide AM radiotelephone communication in the frequency range 225.0 MHz to 399.9 MHz. It operates on any one of 1750 frequency channels with 100 kilohertz spacing at 20 watts power output. A guard channel is provided by a separate guard receiver module incorporated as part of the circuitry of unit 1.

TACAN Units

The TACAN subsystem, units 2 and 3, uses pulsed radio signals from 962 MHz to 1213 MHz to measure aircraft distance and bearing to a TACAN surface station. There are 126 preset channels available to the operator.

Distance-measuring pulses originating in the airborne transmitter are transmitted to the ground radio station which acts as a transponder. Distance of aircraft to station is determined by measuring the elapsed time between the transmission of a challenging or interrogation pulse signal from the airborne transmitter, and the receipt of a corresponding reply pulse from the radio beacon.

Reference bursts and amplitude modulation intelligence are produced in the radio station to provide bearing and identification information for the aircraft. The radio station antenna pattern rotates at 900 rpm and produces a varying field intensity at the receiving antenna. This varying signal intensity produces the 15 Hz and 135 Hz amplitude modulation of the signal received by the airborne receiver. The reference bursts bear a constant relationship to the maximums and minimums of the rotating antenna pattern, and the consequent phase relationship of the AM and the reference bursts received by units 2 and 3 are used to determine the bearing of the aircraft with respect to the radio station.

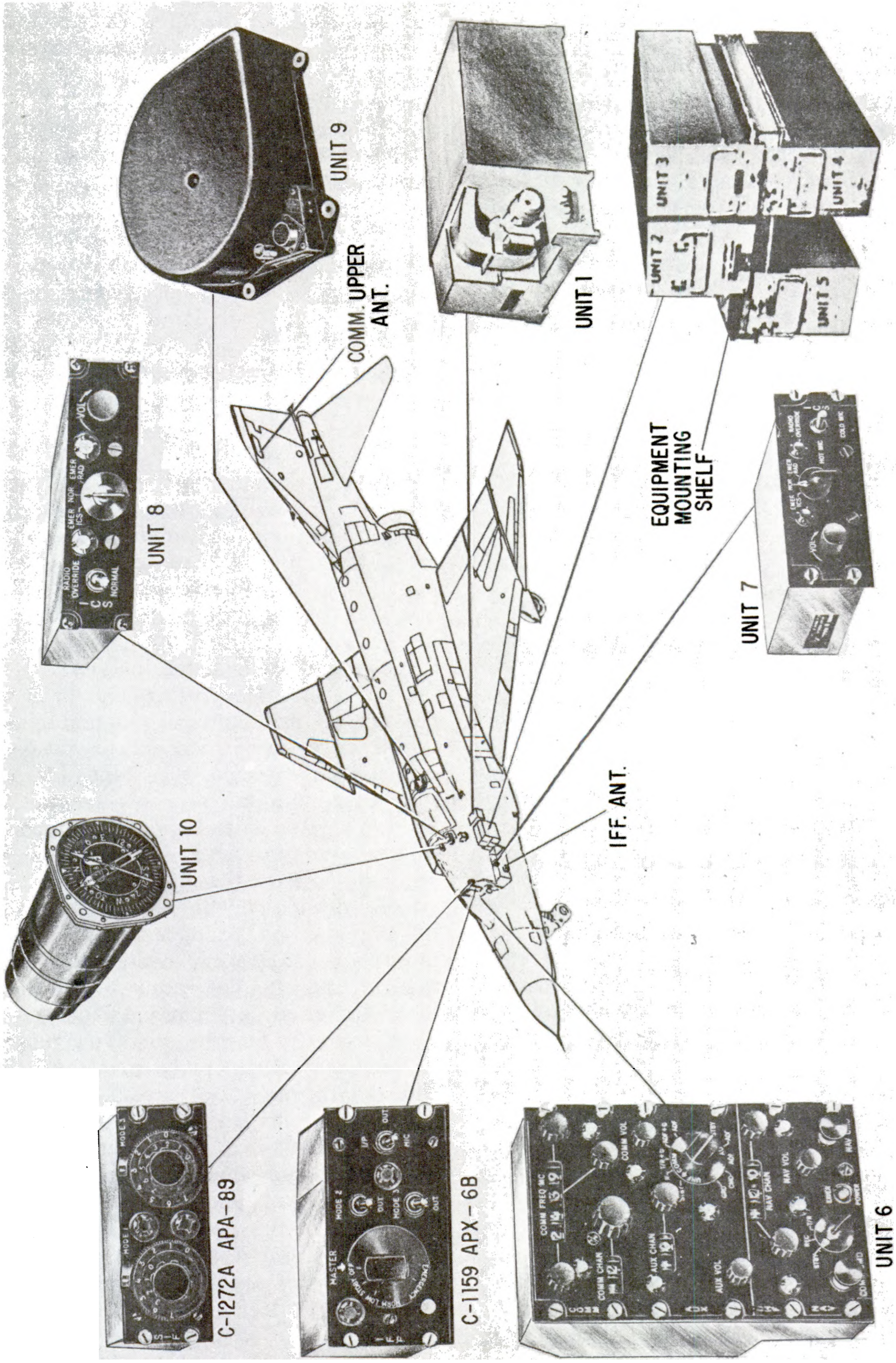

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Figure 16-14.—Integrated Electronic Central AN/ASQ-19.

IFF Coder Unit

The IFF-Coder, unit 4, is a pulse type transponder using a single omnidirectional receiving and transmitting antenna. The equipment normally receives on 1030 MHz and transmits on 1090 MHz. An IFF control box (Radar Set control C-1159/APX-6B) is used to turn on the equipment and to select some of the modes of operation. The various Selective Identification Feature (SIF) reply codes for two of the three challenging signals are set up on an SIF control box (Radar Set Control C-1272A/APA-89). The third SIF code (mode 2) is set up directly on unit 4. Selection of Mark X or SIF replies is made by a switch on unit 4, and cannot be changed during flight.

The airborne antenna receives a challenging signal from interrogator equipment. This consists of pairs of pulses, with a definite time interval between the two pulses of each pair. The receiver detects and amplifies the signal and delivers it to the decoder circuits. If accepted by the decoder circuit in the equipment, the Mark X signal will go directly to the transmitter, and a reply signal is transmitted to the interrogator equipment, where the signal is then displayed on a radar indicator.

If the IFF-Coder is interrogated by an SIF challenge, the decoder output signal goes to a coding circuit in which a reply pulse train is generated. The pulse train is delivered to the transmitter. Upon being received at the interrogator, the pulse train is decoded, and the decoded signal is displayed on the the radar indicator.

Auxiliary Receiver/ADF/Power Supply Unit

The system central power supply portion of unit 5, provides the B + voltages of less than 500 volts necessary for operating all units of the system. The input a-c and d-c power is supplied from two separate sets of aircraft power buses designated main and essential. When an aircraft emergency arises, power is removed from the main buses and the emergency relays are energized automatically, placing the CNI system in emergency operation. The units operating after this emergency switching takes place are the UHF Communications Unit, at reduced power, and the radar identification (IFF) equipment. The ADF and TACAN functions are inoperative since the auxiliary receiver and TACAN B + voltage is removed.

For checking the system on the ground, external power is applied to the main aircraft buses through the ground power connector. A CNI ground power switch located in the left main wheel well is provided and must be manually thrown to energize the equipment. This switch is an electrically held type that must be reset if the ground external power is interrupted. Aircraft power bypasses this switch when the engines are operating; and during flight, the system cannot be deenergized.

The remaining portions of unit 5 are the ADF and the auxiliary receiver. The ADF subsystem uses either the auxiliary receiver in unit 5 or the main receiver, unit 1, in conjunction with the ADF antenna, unit 9, to determine the bearing to a received station. The antenna element has a cardioid pattern which is switched 180° at a 100 Hz rate. The switching action produces modulation on the RF signal (which is detected in the receiver and supplied as an error signal to a servoamplifier). The servosystem positions the antenna element until it is alined with the wave front of the received signal. The antenna maintains this relationship with respect to the signal throughout normal flight maneuvers of the aircraft. The position of the antenna element, relative to the aircraft, is transmitted to the Bearing-Distance-Heading Indicator (BDHI), unit 10, and displayed on the No. 1 pointer. ADF information is also supplied to the Horizontal Situation Indicator (HSI), a part of the instrument system.

The auxiliary receiver in unit 5 is normally used for ADF, and it provides 20 preset channels over the 265.0 MHz to 284.9 MHz range, plus one guard frequency channel at a fixed 243 MHz.

Integrated Control Unit

The communication and navigation functions of the AN/ASQ-19 are controlled by the integrated control, unit 6, selected by the "take command" relays. Two take command pushbotton switches are located on the lower position of each unit 6. One, labeled COM CMD, determines who has control of unit 1. The other, labeled NAV CMD, determines who has control of TACAN. The frequency control for the communication system, the auxiliary receiver, and TACAN are independent of each other. The TACAN function selector also is independent. The function selector switch provides selection of the UHF communication and auxiliary receiver functions.

Intercommunication Units

The intercommunication units, units 7 and 8, of the AN/ASQ-19 provide intercockpit communication in the F-4B aircraft. Unit 7 is the intercom station in the pilot's cockpit; unit 8 is the intercom station in the radar observer's cockpit. An external intercom connection is incorporated into the system for ground personnel. The intercom stations receive and amplify signals from units 1, 2, 3, and the auxiliary receiver of unit 5. In addition, the microphone output in either cockpit is connected to the transmitter of unit 1 by operating the push-to-talk button, thus allowing either pilot or radar operator to communicate. Two transistorized, encapsulated amplifiers are used in units 7 and 8 to amplify the AF output from the microphone and the external audio inputs. Emergency switching facilities allow any one amplifier to be bypassed in the event of their failure. This permits intercockpit communication to be maintained if one amplifier goes dead in each unit.

Antenna System

The antenna system of the F-4B has a pair of antennas, upper and lower, used for both the IFF and TACAN at L band frequencies with two independent automatic antenna switches. The antennas are standard annular slot antennas. A modified blade antenna is mounted in the fin cap and used for the upper communications antenna. A low drag blade is used for the lower antenna. The pilot has the option of selecting either antenna by an antenna selector switch located on the left console of the forward cockpit. The ADF antenna, unit 9 is located on the underside, aft of the radome. This antenna works in conjunction with either the auxiliary receiver or the UHF communication system, whichever is selected for the ADF function on the integrated control box.

Construction

In the CNI system aboard the F-4B aircraft, the modular construction concept has been applied. Circuits have been broken down into functional subdivisions and packaged independently as plug-in modules adhering to a standard size factor. A major functional unit consists of a group of these modules mounted on a chassis in a case which provides interconnecting wiring, radio interference filtering, and cooling distribution.

The modular approach has given a high degree of flexibility in view of the mission and space considerations of this aircraft. It has also reduced costs and accelerated the engineering production cycle, helping to put the full weapon system into the air faster.

Cooling System

Improved thermal design is another important feature of the CNI system. Basically, the problem is to maintain the surface temperature of each component in the system at a value which will insure a high degree of component reliability. This must be done with a cooling system having the smallest possible size and weight.

Neither natural convection and radiation nor the use of integral blowers are acceptable means of cooling if high ambient temperatures (due to local heat dissipation or high aircraft skin temperatures) exist in an equipment rack. The problem is aggravated at extreme altitudes where mass flow from integral blowers drops to negligible values. A forced-air cooling system using an outside source of cooling air is required to hold the component temperatures within acceptable limits.

Since the cooling system must be held to a minimum size and weight, the CNI system is designed to minimize the power dissipation required. Careful circuit design keeps the dissipation in each module as low as practicable. The elimination of individual blowers with their inherent heat dissipation, and the use of a central power supply further reduce the overall heat produced in the system. High temperature components are used as extensively as possible to reduce the amount of cooling air required. Finally, and perhaps most important, the flow of cooling air through each module is carefully controlled to give a high degree of cooling efficiency and still prevent overcooling of any module. In this manner, the required capacity of the cooling system is kept at a minimum, and the reliability and total life of the equipment are extended to a maximum.

COMMUNICATIONS RECEIVERS AND TRANSMITTERS

One of the duties of a technician may be to operate and maintain many different types of aircraft communication equipments. These equipments differ in many respects; however, in other respects they are similar. It is beyond the scope of this training manual to present information that relates to all of the many different equipments; therefore, only representative sets are discussed.

Distinctive features of naval airborne communications equipment include automatic tuning, subassembly and modular types of construction, shock mounting of major units, and pressurization, as well as the electronic components and circuitry employed.

Automatic tuning, which makes possible rapid selection of preset channels, is used in most modern naval airborne communication systems. This feature is essential because channel changes must be made accurately and quickly. Since the automatic system provides great simplicity of control, the entire operation is usually accomplished by means of a single dial.

The use of shock mounting is required because of vibration and the extreme physical forces present in normal operation in aircraft. The construction of electronic equipment in subassemblies and modules simplifies maintenance and repair. It permits the removal and replacement of sections containing defective or malfunctioning parts without dismantling the entire equipment.

All radio communication equipments, whether military or civilian, are designed for operation within certain well-defined frequency limits. In this chapter the terms used in reference to frequency bands designate major portions of the radio spectrum as discussed in chapter 9 of this manual. The designations and abbreviations are those in general use.

GENERAL PURPOSE RECEIVER AN/ARR-41

Radio Receiving Set AN/ARR-41, consisting of the receiver R-648/ARR-41 and its mounting, is a radio receiver that finds general application in naval aircraft. It is a superheterodyne receiver capable of receiving RF signals from 190 kHz to 550 kHz and from 2 MHz to 25 MHz, covered in five frequency bands. A mechanical type counter, located on the front panel of the receiver, indicates the frequency (in megahertz) of the received signals. It can receive signals which are of the AM, unmodulated CW, or frequency shift keyed types. Accurate frequency calibration is obtained through a built-in circuit consisting of a 500 kHz crystal-controlled oscillator and a multivibrator. Construction is of the subassembly design.

The Service Instruction Manual for the receiver presents in detail the theory and operation of the receiver, the maintenance, test, and alinement procedures and specifications, and the complete list of test equipment required. Only a brief summary of the theory of operation of the (R-648) ARR-41 is presented in this chapter.

Theory of Operation

This receiver employs double conversion; that is, all received RF signals (except for band 2) are first converted to a variable IF, amplified, and then converted to a fixed IF. (Band 2 covers the range of 2 megahertz to 4 megahertz; signals within this band are shunted around the first converter, or mixer.) Some of the benefits obtained by double conversion are high gain and sensitivity.

For CW reception the set employs a beat frequency oscillator (BFO), with a control for variable pitch or tone. A CW signal contains no modulation, so a separate oscillator must be built into the receiver in order to receive CW. The principle of the BFO is discussed in Basic Electronics, NavPers 10087-B.

Figure 16-15 is a block diagram of the receiver. Reference to this diagram, in connection with the discussion that follows, simplifies the explanation of the receiver's operation. Particular attention should be paid to the direction of the arrows.

The incoming RF signal is received by the antenna and applied to one of five tuned circuits, depending upon the band of reception. The signal is then applied to the grid of the first RF amplifier, V701, for amplification. After the first stage of RF amplification, frequencies within the range of bands 1, 3, 4, and 5 are applied through tuned circuits to the second RF amplifier and then through more tuned circuits to the first mixer, V703. The function of the first mixer is to heterodyne the output of the RF oscillator, V601, with the incoming RF and produce a variable IF of 2 MHz to 4 MHz. Band 2 frequencies are 2 MHz to 4 MHz without heterodyning and therefore are switched around the second RF amplifier and first mixer circuits. (The switches in the block diagram are shown in band 2 position.)

At this point, any signal, regardless of the original frequency, is within the range of 2 MHz to 4 MHz and is applied through the variable IF tuned circuits to the variable frequency oscillator converter, V15001. Mixer V15001 heterodynes the variable IF 2 MHz to 4 MHz signal with a locally generated 2.5 MHz to 3.5 MHz signal, producing an output of 500 kHz, the fixed intermediate frequency.

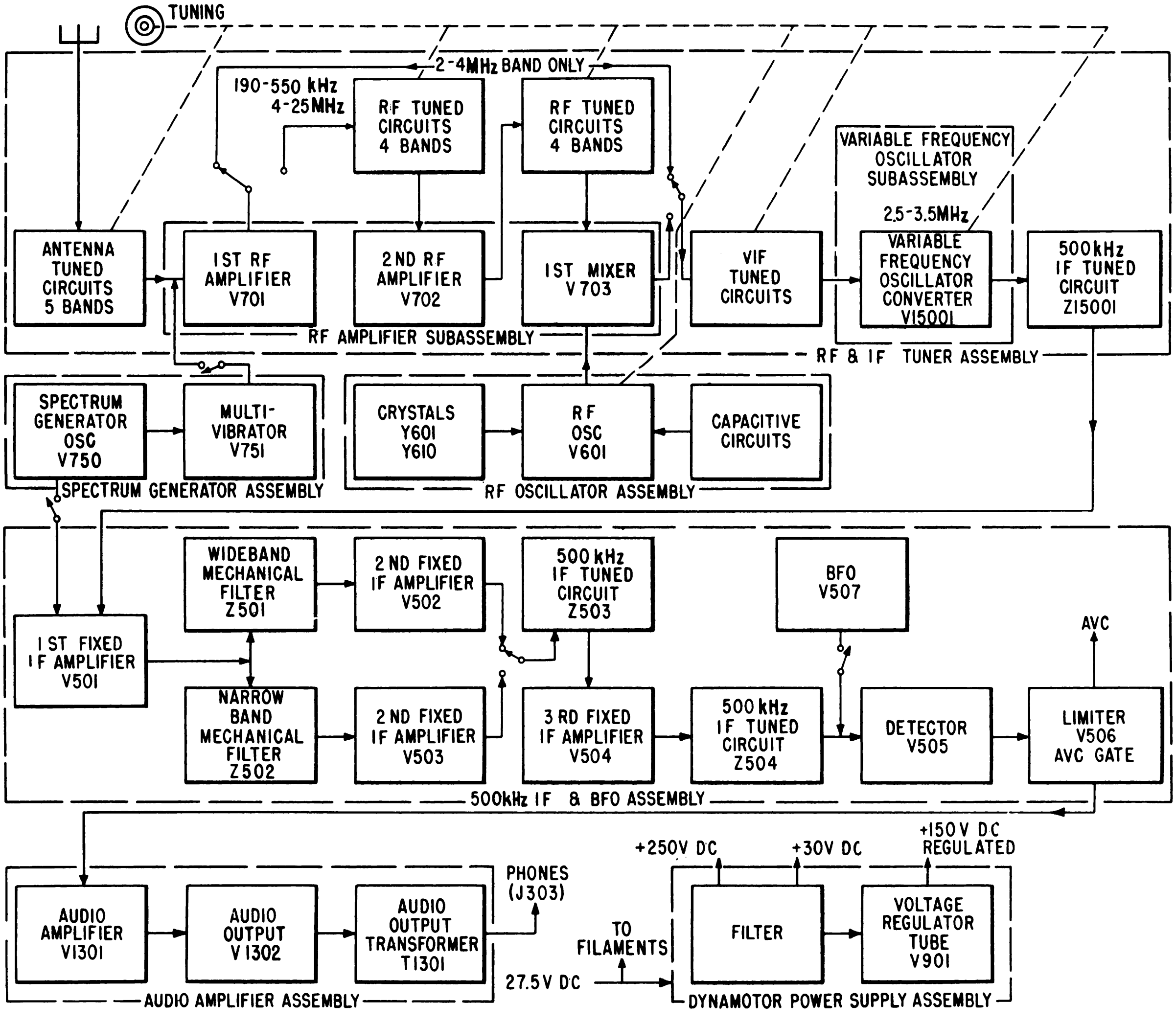
TUNING
2-4MHz BAND ONLY
190-550 kHz
4-25MHz
RF TUNED CIRCUITS 4 BANDS
RF TUNED CIRCUITS 4 BANDS
VARIABLE FREQUENCY OSCILLATOR SUBASSEMBLY
2.5-3.5MHz
ANTENNA TUNED CIRCUITS 5 BANDS
1ST RF AMPLIFIER V701
2ND RF AMPLIFIER V702
1ST MIXER V703
VIF TUNED CIRCUITS
VARIABLE FREQUENCY OSCILLATOR CONVERTER V15001
500kHz IF TUNED CIRCUIT Z15001
RF AMPLIFIER SUBASSEMBLY
RF & IF TUNER ASSEMBLY
SPECTRUM GENERATOR OSC V750
MULTI-VIBRATOR V751
CRYSTALS Y601 Y610
RF OSC V601
CAPACITIVE CIRCUITS
SPECTRUM GENERATOR ASSEMBLY
RF OSCILLATOR ASSEMBLY
WIDEBAND MECHANICAL FILTER Z501
2ND FIXED IF AMPLIFIER V502
500kHz IF TUNED CIRCUIT Z503
BFO V507
AVC
1ST FIXED IF AMPLIFIER V501
NARROW BAND MECHANICAL FILTER Z502
2ND FIXED IF AMPLIFIER V503
3RD FIXED IF AMPLIFIER V504
500kHz IF TUNED CIRCUIT Z504
DETECTOR V505
LIMITER V506 AVC GATE
500kHz IF & BFO ASSEMBLY
+250V DC
+30V DC
+150V DC REGULATED
PHONES (J303)
AUDIO AMPLIFIER V1301
AUDIO OUTPUT V1302
AUDIO OUTPUT TRANSFORMER T1301
TO FILAMENTS
FILTER
VOLTAGE REGULATOR TUBE V901
27.5V DC
AUDIO AMPLIFIER ASSEMBLY
DYNAMOTOR POWER SUPPLY ASSEMBLY

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Figure 16-15.–Block diagram of Radio Receiver R-648/ARR-41.

The 500 kHz signal is applied to the grid of V501 for first IF amplification. This output passes through either a broad band or narrowband mechanical filter (fully explained in chapter 16 in connection with single sideband) and through one of two second IF amplifiers. Bandwidth selection (broad or narrow) depends upon the setting of the emission switch. The IF signal is then applied through another tuned circuit to the grid of the third IF amplifier, V504, the plate circuit of which contains the IF tuned circuit Z504. Tuned circuit Z504 couples the output of IF amplifier V504 to the detector tube V505. The functions of V505 are to recover the modulation component of the IF signal (detection) and to produce a negative voltage proportional to the carrier level for automatic volume control (AVC).

The BFO may be switched into the detector input by operation of the emission switch to the CW or CW SHP positions. In this manner a beat note is produced with the 500 kHz IF signal, which is a variable tone to be used for CW reception. Output from the detector is applied to V506, the limiter and AVC gate. One-half of dual diode V506 functions as an AVC gate control and prevents application of AVC voltage to the various amplifiers until full receiver sensitivity has been reached. The other half of V506 is a noise limiter which suppresses undesired noise pulses. The output of V506 is an audio voltage proportional to the modulation of the incoming RF signal. Audio amplifier V1301 and audio output V1302 serve to amplify the audio signal. Phone jack J303 is connected to audio output transformer T1301, and is available on the front panel of the receiver.

The spectrum generator consists of a crystal-controlled oscillator and a multivibrator divider circuit. The crystal-controlled oscillator, V750, serves to produce an accurate 500 kHz signal. The 500 kHz signal is applied to the grid of the first IF amplifier, V501, and to one plate and grid of the multivibrator divider, V751. The multivibrator fires on every fifth input pulse and produces an output, to the first RF amplifier, of 100 kHz. This 100 kHz output signal is rich in harmonics and allows the RF circuits to tune to a particular harmonic, depending upon the resonant frequency of the tuned circuits. A beat note is produced as a result of heterodyning the 500 kHz signal applied to the first IF amplifier with the selected harmonic of the multivibrator. This beat note is heard when the receiver frequency is varied around the selected multivibrator harmonic and the correct receiver frequency is known on the basis of the counter reading. The counter may then be set to the exact 100 kHz multiple and calibration is completed.

Operation

Complete details regarding the operating procedures of the AN/ARR-41 are contained in the Operation Instruction Manual, NavAer 16-30ARR41-501. This discussion is presented only to provide a few details concerning capabilities of the receiver.

The emission selector switch has two positions which are used when noise interferes with reception of voice or CW signals. By switching to either of these two sharp positions, a narrowband filter is inserted into the IF circuit to reduce the effective noise level.

Selected frequency is indicated on three counter dials. Selected band is indicated on a fourth dial located immediately to the left of the frequency counters. Interpolation to within 0.1 kHz is made possible by the arrow located to the right of the right-hand counter.

Calibration and Maintenance

Calibration and maintenance procedures and specifications are contained in the Service Instruction Manual, NavAer 16-30ARR41-502. Organizational maintenance is made relatively easy and rapid because of the interchangeable subassembly type construction of the unit.

VHF TRANSCEIVER AN/ARC-44

Radio Set AN/ARC-44 is a subminiature airborne frequency modulated receiver-transmitter. It operates in the frequency range of 24.0 MHz to 51.9 MHz. Its primary function is to provide two-way voice communications between aircraft, or between an aircraft and ground stations. Normally, use of the equipment is limited to line-of-sight distances; by use of a retransmit feature (which requires a dual installation of AN/ARC-44) the equipment can serve as a radio relay, thus extending the operating distance. A second auxiliary function permits use of the equipment to home on any station within range. Another feature permits control of the other radio transmitters and receivers and the ICS equipment through the AN/ARC-44 control box switches.

The AN/ARC-44 is installed primarily in older type aircraft. It is not part of any specific integrated system, but is adaptable to almost any communication/navigation system in present use.

Input power requirement for the equipment is limited to 27.5 volts d.c. from the main aircraft supply. A dynamotor is used to convert the input power into +150 volts d.c., -150 volts d.c., and 27 volts 400 hertz single-phase a.c. These output voltages are then distributed to the appropriate circuits throughout the equipment.

Interunit connecting wiring is primarily of the cable harness type. Multiple-pin receptacles are mounted on each unit and mounting rack, with a central terminal box used to terminate the other end of each cable. Necessary connections are made within the terminal box.

Cooling of the main receiver-transmitter unit is accomplished by means of an exhaust air blower. Air leaks into the unit from its immediate surroundings, the air is heated by the operating equipment, and is then exhausted back into the space surrounding the equipment.

Double-conversion superheterodyne circuits are used in conjunction with the receiver circuits to change an incoming modulated RF signal in the range of 24.0 MHz to 51.9 MHz to a modulated IF signal of 2.9875 MHz; they are used in conjunction with the transmitter circuits to change a modulated 2.9875 MHz oscillator signal to a modulated RF output between 24.0 MHz to 51.9 MHz. In each case, the change is accomplished in two mixer stages.

Frequency modulation of the transmitted signal is accomplished by use of a reactance tube modulator and a "sidestep" oscillator. These stages produce a 2.9875 MHz carrier which is modulated by the incoming audio signal. (See fig. 16-16.)

The sidestep oscillator is a Lampkin type oscillator. It employs a free-running, temperature compensated circuit and operates at a center frequency of 2.9875 MHz. The oscillatory tank circuit consists of L1703 and C1707, together with trimmer C1708. The portion of L1703 between C1705 and a-c ground (at the top of C1706) is common to both the plant and grid circuits. It is through this common path that regenerative feedback occurs continuously.

One side of C1708 is placed at a-c ground potential to facilitate mounting of this capacitor. The tuning range of C1708 is determined by the position of the L1703 tap for feedback coupling capacitor C1705. Resistor R1706 is the grid leak resistor.

The advantage of this type of oscillator is that variations which occur in tube characteristics have a minimum effect on the tank circuit frequency. Temperature compensation within the tank circuit is achieved by making the end plate of C1707 from a bimetallic material. Any variations in tank coil inductance produced by temperature variations will be compensated by capacitance variations in C1707.

RF voltages appearing across the oscillator tank also appear across the phase shifting network in the modulator input by way of d-c blocking capacitor C1710. This network consists of resistor-capacitor combinations R1709/C1709 and R1712/C1711 plus the internal resistance (plate-cathode circuit) of V1703. The voltage drop across C1711, by reason of the phase-shifting network, lags the tank voltage by 90°. Since the modulator RF plate current responds in the same phase as the grid voltage, it also lags the tank voltage by 90°. The RF plate current flows through the tank circuit and vectorially adds with the current therein to produce a resultant current differing in phase from the original tank current. This is equivalent to adding a reactance to the oscillator tank or, in other words, to changing the oscillator frequency.

Because of the phase difference existing between the modulator plate current component and the original oscillator tank current component, the phase of the resultant current depends on the magnitude of either of these out-of-phase components. This characteristic is used to produce the frequency modulation.

Audio voltages applied to the control grid of the modulator change the magnitude of the RF plate current in direct proportion to the audio voltage swing. Thus, due to the changing RF plate current components, the phase of the resultant tank current (and the frequency of the

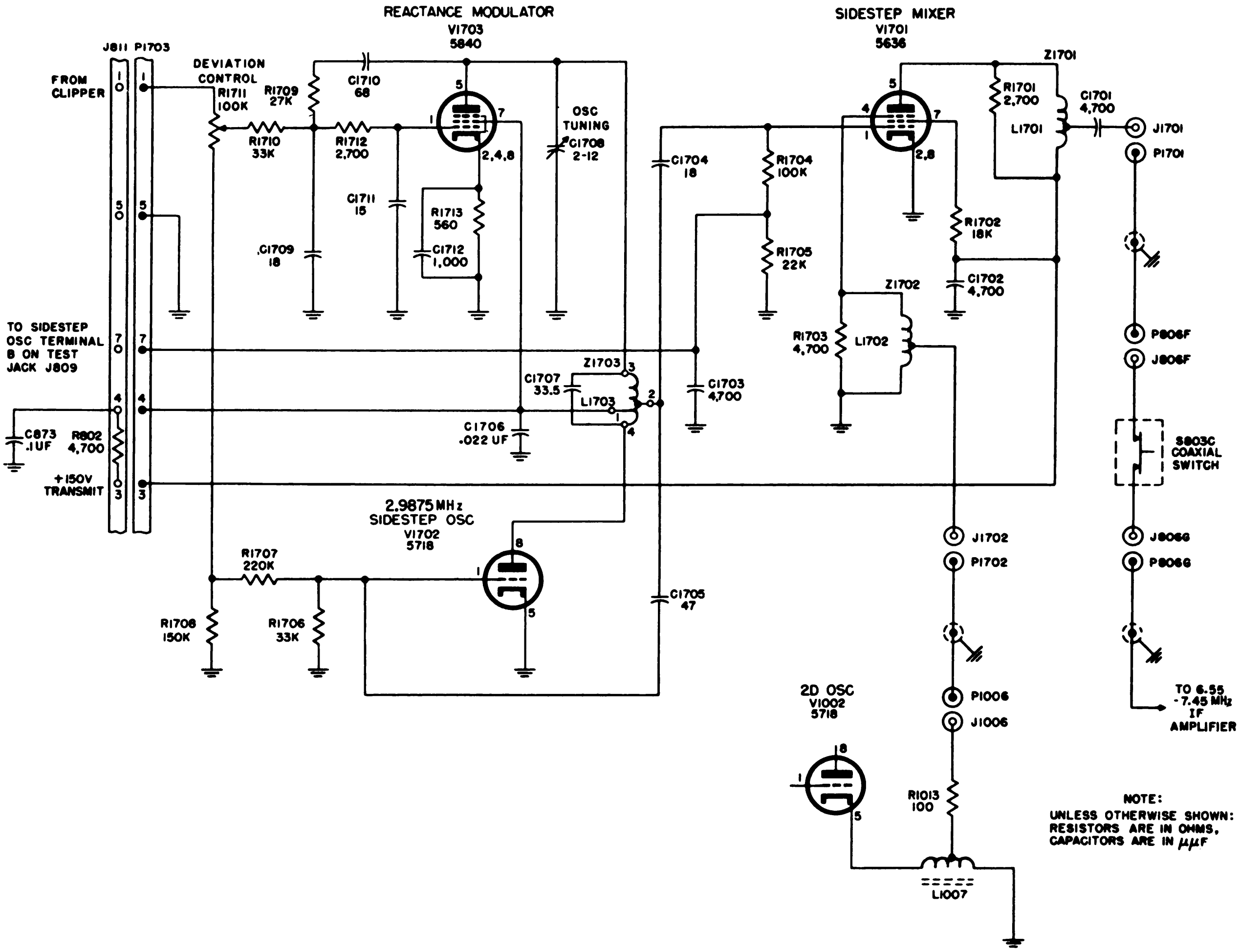

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Figure 16-16.–Reactance modulator and sidestep circuits.

oscillator) varies in accordance with the amplitude variations of the audio signal.

Selection of operating frequency is accomplished through use of a tuning drive mechanism, which automatically adjusts the appropriate stages of both the receiver and transmitter.

Additional details concerning Radio Set AN/ARC-44 may be found in NavWeps 16-30ARC-44-1.

SINGLE SIDEBAND TRANSCEIVER AN/ARC-94

Radio Set AN/ARC-94 provides facilities for communication between aircraft, and between aircraft and fixed or mobile ground communications stations. The AN/ARC-94 transmits and receives communications in the high-frequency (HF) band and can operate over the 28 megahertz band between 2,000 megahertz and 29.999 megahertz. The set includes Radio Receiver-Transmitter RT-648/ARC-94, Radio Set Control C-3940/ARC-94, and Mounting MT-2641/ARC-94. The RT unit is of modular construction for ease of maintenance. In addition to the set components, the complete aircraft installation requires a headset, microphone, key, antenna coupler, and antenna.

The RT unit functions as a part of an overall HF communications system. Frequency selection is in increments of 1 kHz over the entire band, providing a choice of 28,000 operating frequencies.

The control unit provides for remote selection of operating frequency, and for selection of upper sideband, lower sideband, amplitude modulation, data link, or CW mode of operation.

The mounting provides for mechanical support and isolation from airframe vibration and shocks.

Operation of the set, as discussed briefly in the following paragraphs, is divided into a transmit function, a receive function, and a carrier generator function which is common to both reception and transmission. The brief discussion is in block diagram form. (Refer to fig. 16-17 in connection with the discussion.) Principal intelligence signal flow is indicated by heavy lines.

The diagram is divided functionally rather than by the physical location of the parts.

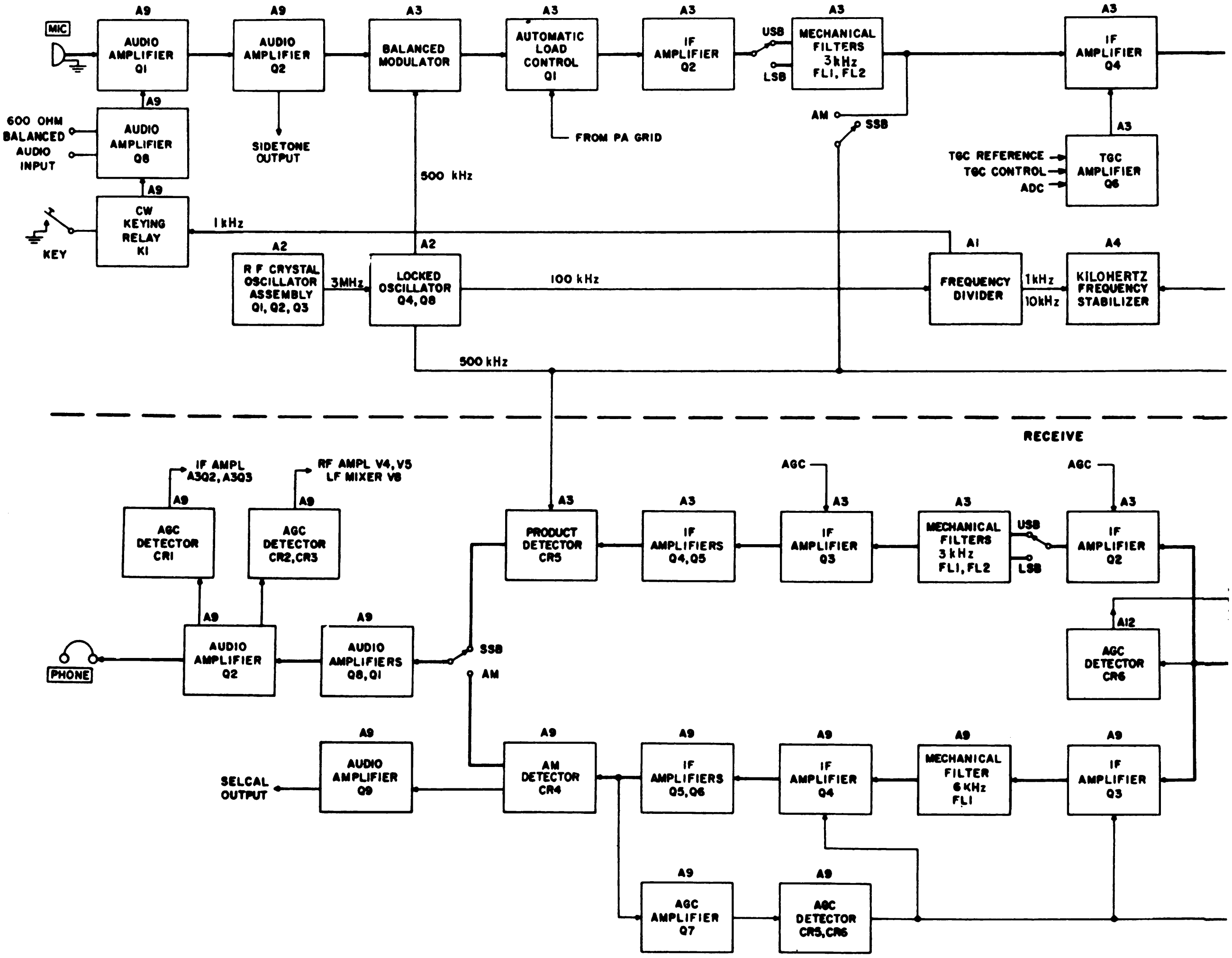

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Figure 16-17.–AN/ARC-94, simplified block diagram.

Blocks and individual component parts mentioned in the discussion are referenced in the standard manner for modular construction. Modules are referenced as A1, A2, etc. Where detail parts are considered in a discussion, the module designation and the part designation are combined into a compound reference, such as A1R2, A2R2, etc., to indicate the module and specific part. Parts located on submodules are designated by a triple compound designation such as A12A2C3, where A12 is the module, A2 is the submodule, and C3 is the detail part of interest.

Transmit Function

The transmit function includes an AF input section, an IF translator section, an RF translator section, and a power amplifier section.

The AF input section provides coupling and amplification for the voice intelligence to be transmitted. The IF translator section contains the circuitry for selecting the desired mode of operation and the stages that modulate and process the desired signal accordingly. The RF translator section performs the final conversion

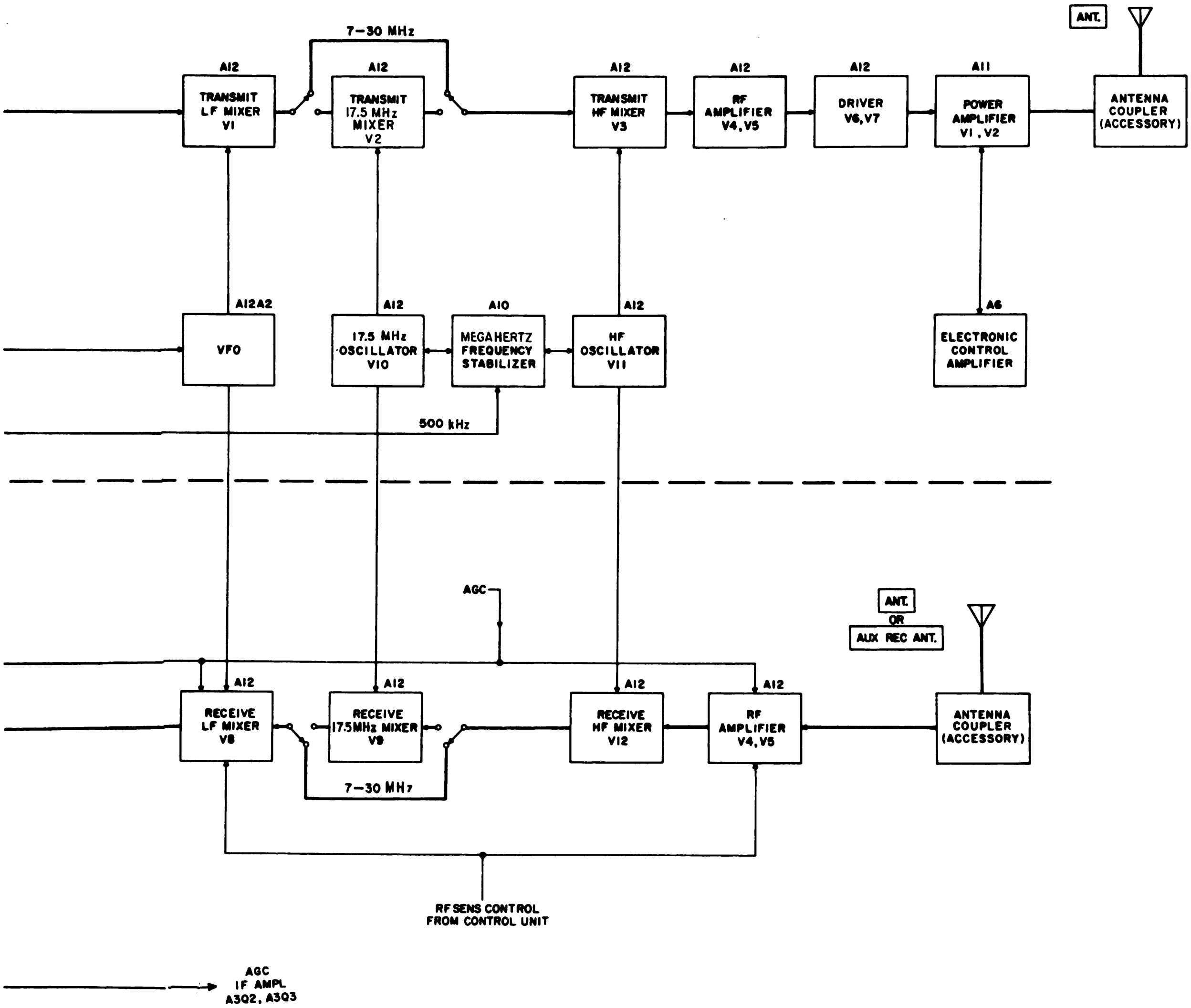

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Figure 16-17.–AN/ARC-94, simplified block diagram–Continued.

step in translating the modulated signal information to the frequency band selected for transmission. The carrier generator function provides all the frequencies required for the double conversion transmit function The carrier generator function also provides all the frequencies required for demodulating in the receive function. Tuning is carried out within the carrier generator function by means of an autopositioner system similar to that of the AN/ARC-88.

AF INPUT SECTION.–An audio signal from the operator's microphone, fed into the 100-ohm, unbalanced input, is amplified in audio amplifier stages A9Q1 and A9Q2 and applied to the balanced modulator in the IF translator section.

When a 600-ohms balanced audio input is used, the signal is preamplified by audio amplifier A9Q8 before being applied to A9Q1 and A9Q2.

When the transmitter is operating in the CW mode, a 1 kHz audio signal is obtained from frequency divider module A1. This 1 kHz signal is then fed from CW keying relay A9K1 to the audio input.

IF TRANSLATOR SECTION.–The audio signal from the AF input section and a carrier signal from locked oscillators A2Q4 and A2Q8 in the carrier generator function are combined in the balanced modulator. The balanced modulator yields a suppressed carrier amplitude modulated output consisting of upper and lower sidebands. The balanced modulator output is fed to automatic load control A3Q1, which is controlled by a signal fed back from the power amplifier in the power amplifier section. The output level of the automatic load control stage is adjusted by the feedback voltage to maintain the transmitter output at a predetermined level. From A3Q1, the signal is applied to A3Q2 through relay A3K5. The desired signal is then amplified by IF amplifier A3Q2 and applied to the mode selector.

The mode selector provides the option of operating in either SSB, AM, data, or CW mode. In SSB mode, the further option of using USB or LSB is provided.

In AM mode, the double-sideband suppressed carrier signal is applied to 3 kHz mechanical filter A3FL1, which passes only the upper sideband. A 500 kHz carrier signal from the carrier generator function is reinserted into the upper sideband at the output of filter A3FL1.

In SSB mode, the carrier reinsertion capability is disabled. The double-sideband suppressed carrier output of A3Q2 is switched to a 3 kHz mechanical filter, either A3FL1 or A3FL2, depending on the setting of the mode selector. Filter A3FL1 passes only the USB and A3FL2 passes only the LSB. The sideband not passed is suppressed. An intelligence consisting of a USB or LSB signal is then fed through relay A3K5 to IF amplifier A3Q4.

The data and CW modes are similar in function to the SSB modes since USB is always used for data and CW operation.

The desired signal is amplified in A3Q4 and fed to transmit LF mixer A12V1. Transmitter gain control amplifier A3Q6 controls the output transmission level by adjusting the gain of A3Q4 in accordance with control voltages provided in the form of a transmitter gain control signal and an automatic drive control signal.

RF TRANSLATOR SECTION.–The desired signal is mixed in A12V1 with a preselected output from the variable frequency oscillator in the carrier generator function. The output circuit of A12V1 is tuned to the difference frequency of the two signal inputs to the mixer. The frequency range of the output signal from the transmit LF mixer is 2.001 MHz to 3.000 MHz in 1 kHz increments. If the selected output frequency is to be in the range of 2.0 MHz to 6.999 MHz, the LF mixer output signal is coupled to transmit 17.5 MHz mixer A12V2. A signal is also applied to A12V2 from 17.5 MHz oscillator A12V10. The output circuit of A12V2 is tuned to the difference frequency of the two signals to produce an output frequency in the range of 14.5 MHz to 15.5 MHz. If the selected output frequency is to be in the 7.0 MHz to 30.0 MHz range, the output of A12V1 is coupled directly to A12V3. A signal is also applied to A12V3 from HF oscillator A12V11. The difference frequency of the two input signals mixed in A12V3 is at the desired output frequency and is amplified by RF amplifiers A12V4 and A12V5 and fed to drivers A12V6 and A12V7. The driver output is fed to power amplifiers A11V1 and A11V2.

POWER AMPLIFIER SECTION.–The power amplifier is band-switched by the autopositioner and tuned by a servo-driven inductance in electronic control amplifier module A6. The output of the power amplifier is designed for a 52-ohm unbalanced load and is applied to the transmitting antenna through an antenna coupler.

Receive Function

The receive function includes an RF input section, a first and second conversion section, an SSB channel, an AM channel, and an audio section.

The RF input section receives the desired signal broadcast by the remote station. The signal is amplified and sent to the first and second conversion sections, where a double conversion is performed to bring the signal to the desired intermediate frequency. In SSB, data, and CW modes, the AM channel is disabled and the desired signal is brought to the SSB channel. After being amplified to a suitable level, the desired SSB signal is demodulated in a product detector. The resultant audio signal is amplified in the audio section and applied to headset phones.

In AM mode, the SSB channel is disabled and the desired signal is brought to the AM channel. In the AM channel, a standard AM detector is used to demodulate the signal. All other functions are similar to those which occur in the SSB channel.

COMMON STAGES.–The receive function of the AN/ARC-94 uses many stages in common with the transmit function. Function selection is controlled by the operator with a push-to-talk switch. When the switch is operated, the transmit function is actuated. At all other times the receive function is actuated. A relay operated switching system shifts the assignments of the common stages between transmit and receive functions as required.

RF INPUT SECTION.–The RF input section receives the desired signal from a remote station. The impedance of the antenna is matched to that of amplifiers A12V4 and A12V5 by a suitable coupler device to insure maximum energy transfer. The amplifiers step up the received signal and apply it to receive HF mixer A12V12 in the first conversion group. RF gain is manually adjustable from the C-3940/ARC-94. The RF amplifiers are also under AGC system control.

CONVERTER SECTION.–The output of A12V4 and A12V5 is fed to receive HF mixer A12V12 where it is mixed with the signal from HF oscillator A12V11 in the carrier generator section. The output of A12V12 is coupled to receive 17.5 MHz mixer A12V9 if the operating frequency is in the range of 2.0 MHz to 6.999 MHz. It is coupled to receive LF mixer A12V8 if the operating frequency is in the range of 7.0 MHz to 30.0 MHz. The output from A12V8 is a 500 kHz IF signal. The 500 kHz IF signal is fed to either the SSB or AM channel.

SSB AND AM CHANNELS.–In SSB mode, the 500 kHz IF signal is applied to one of two mechanical filters, A3FL1 or A3FL2. Each mechanical filter has a bandwidth of 2.7 kHz. One filter passes the upper sideband, and the other passes the lower sideband. The appropriate filter is selected at the mode selector on the C-3940/ARC-94. The filter output is amplified in IF amplifiers A3Q3, A3Q4, and A3Q5. The output of A3Q5 is applied to product detector A3CR5 which recovers the audio signal.

In AM mode, the output of A12V8 is fed to IF amplifier A9Q3 for amplification and is coupled to 6 kHz mechanical filter A9FL1. The signal is then fed to three more IF amplifiers, A9Q4, A9Q5, and A9Q6. The output of A9Q6 is fed to diode detector A9CR4 which recovers the audio signal and applies it to the audio section.

AUDIO SECTION.–In either channel, the desired audio signal is amplified in audio amplifiers A9Q1, A9Q8, and A9Q2, and fed to the operator's headset. Selcal (selective calling) signals detected in AM detector A1CR4 are fed to audio amplifier A9Q9 and are coupled to the rear connector of the RT-648/ARC-94. Selcal signals are detected in all modes of operation.

Carrier Generator Function

The carrier generator function includes RF oscillator A2, frequency divider A1, kilohertz-frequency stabilizer A4, variable frequency oscillator (VFO) A12A2, 17.5 MHz oscillator A12V10, megahertz-frequency stabilizer A10, and HF oscillator A12V11.

FREQUENCY GENERATION AND STABILIZATION.–The AN/ARC-94 transmits and receives on every 1 kHz increment from 2,000 MHz to 29.999 MHz. This provides 28,000 possible separate operating frequencies. The operating frequency is selected at the C-3940/ARC-94. The 100 kHz, 10 kHz, and 1 kHz frequency selector knobs on the C-3940/ARC-94 actuate autopositioner A12A1. The autopositioner mechanically tunes variable frequency oscillator A12A2 over the range from 2.501 MHz to 3.500 MHz in 1 kHz increments. The megahertz frequency selector knob on the C-3940/ARC-94 controls a motor in RF translator module A12. This motor switches tuning elements which tune HF oscillator A12V11 to one of 28 different frequencies. The HF oscillator, in conjunction with 17.5 MHz oscillator A12V10, provides 28 1 MHz bands for each of the 1 kHz increments from variable frequency oscillator A12A2.

Megahertz-frequency stabilizer module A10 stabilizes the frequency of A12V10 and A12V11 by comparing each oscillator frequency with the frequency of a spectrum point derived from the 500 kHz output of RF oscillator module A2. The coarse frequency of A12V11 is controlled by the motor in RF translator module A12. The frequency range of A12V11 is 8.5 MHz to 32.0 MHz. The output of A12V11 is tuned to the second harmonic of the fundamental oscillator frequency when the selected operating frequency of the RT-648ARC-94 is in the range of 14.0 MHz to 29.999 MHz. This signal is coupled to transmit HF mixer A12V3, and to receive HF mixer A12V12.

The extremely high stability of the AN/ARC 94 operating frequency is obtained by basing frequency control of the entire RT-648/ARC-94 on the frequency of a very stable crystal oscillator located in RF oscillator module A2. Frequency stability of this crystal oscillator is assured by utilizing a temperature-compensating network.

The HF and 17.5 MHz oscillators are frequency locked, and the variable frequency oscillator is phase locked to the crystal generated reference frequency by circuits in the megahertz- and kilohertz-frequency stabilizer modules. The IF injection frequency is derived from the crystal oscillator. The RT-648/ARC-94 operating frequency is thus held accurate within ±0.8 part per million per month from -40° C (-40°F) to +75°C (+167°F).

Keying Circuits

When the RT-648/ARC-94 is keyed, the keying circuits actuate the stages that must operate if the RT-648/ARC-94 is to transmit, while disabling receiver circuits that would interfere with transmission. When the key is released the keying circuits operate to switch off the transmitter and switch common stages from the transmit to the receive function.

Sidetone Circuits

The sidetone signal is taken from audio amplifier stage A9Q2 to provide audio monitoring in the transmit mode. The audio signal from the audio amplifier is fed through a keying relay and a sidetone relay (not shown) to the audio output. A combination of two voltages is used to energize the sidetone relay.

One voltage is derived from the RF output of power amplifier module A11. This RF output is rectified, filtered, and applied to the sidetone relay coil.

The second voltage, from three-phase high-voltage power supply module A7 (not shown) is proportional to the power amplifier plate current. This voltage is the same one used for transmitter gain control in IF translator module A3. To energize the sidetone relay, sufficient plate current and plate voltage swing must be present in the power amplifier. A capacitor is placed across the coil of the sidetone relay to keep the relay energized in the sideband transmit mode when the plate current varies with the applied audio signal.

Recycle Circuits

The recycle circuits are activated when any of the frequency selector knobs on the C-3940/ARC-94 are turned. When any autopositioner operates, the recycle relay (not shown) is energized, and remains energized so long as any tuning motor is operating. The recycle relay has the following functions:

1. Disconnects transistor supply voltage to the audio amplifier in order to mute the audio during the tuning cycle.
2. Provides a ground to activate the antenna tuner.
3. Interrupts the operation of kilohertz-frequency stabilizer module A4 during the tuning cycle.

4. Disconnects the keying circuit so that the transmitter cannot be keyed during the tuning cycle.

UHF TRANSCEIVER (FM) AN/ARC-88

The purpose of Radio Set AN/ARC-88 is to provide a UHF frequency-modulated radio link between aircraft, shore, and ship. Radio Receiver-Transmitter RT-649/ARC-88 is a partially transistorized equipment capable of transmitting and receiving on any one of 1750 frequency channels, spaced at 100 kHz intervals in the 225.0 MHz to 399.9 MHz range. The equipment receives and transmits multiplexed data information originating in the form of digital pulses from an associated equipment of a digital data communication system.

Radio Set AN/ARC-88 is supplied digital information from the associated data equipment and transmits it on a frequency modulated carrier signal. It also receives a similar frequency-modulated signal, demodulates the signal, and supplies the resulting pulses to the associated data equipment. Reception and transmission are on the same frequency and utilize the same antenna.

Radio Set Control C-2736A/AR provides remote selection of the 1750 frequency channels or 19 preset channels within the specified range. (The frequencies of the 19 preset channels are determined by adjustment of a memory drum on the front panel.)

Major Components

Radio Set AN/ARC-88 consists of Radio Receiver-Transmitter RT-649/ARC-88, Mounting MT-2653/ARC, Standing Wave Ratio Indicator IM-178/ARC-88. Electronic Equipment Air Cooler HD-513/ARC, and Radio Set Control C-2736A/AR. The following paragraphs provide a brief description of these components, followed by a brief discussion of the general principles of operation of the equipment.

RECEIVER-TRANSMITTER.–Radio Receiver-Transmitter RT-649/ARC-88 consists of a main chassis, dust cover, and nine plug-in modules. The nine plug-in modules are mounted on the main chassis and enclosed in an aluminum case. An airtight seal is provided between the cover and the main chassis to permit the modules of the component to be pressurized. External cooling air is forced by the external blower through the base casting to the heat exchanger and expelled at the bottom of the unit. (See fig. 16-18.) Internal air is circulated through the internal cores of the heat exchangers, through the plenum chamber formed by the main chassis, and through each module by an internal blower. In this manner, the heat from the component is dissipated.

An antenna, two power connectors, and a pressurizing valve are mounted on the front panel. A toolkit containing special tools for maintenance is supplied with Radio Receiver-Transmitter RT-649/ARC-88.

MOUNTING.–Mounting MT-2653/ARC provides a mounting base for Radio Receiver-Transmitter RT-649/ARC-88. Vibration isolators which are usually a part of the mounting are an integral part of the mounting base casting of the RT-649/ARC-88.

SWR INDICATOR.–Standing Wave Ratio Indicator IM-178/ARC-88 provides the operator with a remote indication of transmitter power output. It is secured to the front panel of the RT unit by three cross-recessed screws. When the set is in transmit operation, the remote meter indicates incident power. By changing the connection of the remote power indicator to the other wire on the multiwire cable, a reflected power measurement may be obtained.

AIR COOLER.–Electronic Equipment Air Cooler HD-513/ARC is made up of a casting, single-phase blower motor, and an air inlet filter assembly. It is secured to the rear of the RT unit by four hex-socket screws. The HD-513/ARC operates when the internal temperature of the RT unit exceeds 35°C (95°F).

CONTROL UNIT.–Radio Set Control C-2736/AR is used to control Radio Receiver-Transmitter RT-649/ARC-88. A selector switch on the front panel makes 19 preset channels available to the operator. This selector switch has complete control of selection unless it is set to the M position. In the M position, adjustment of the four MANUAL frequency controls operates switches which activate an autopositioner, located in the RT unit, to set up operation at the selected frequency. A three-position rotary power switch on the front panel controls

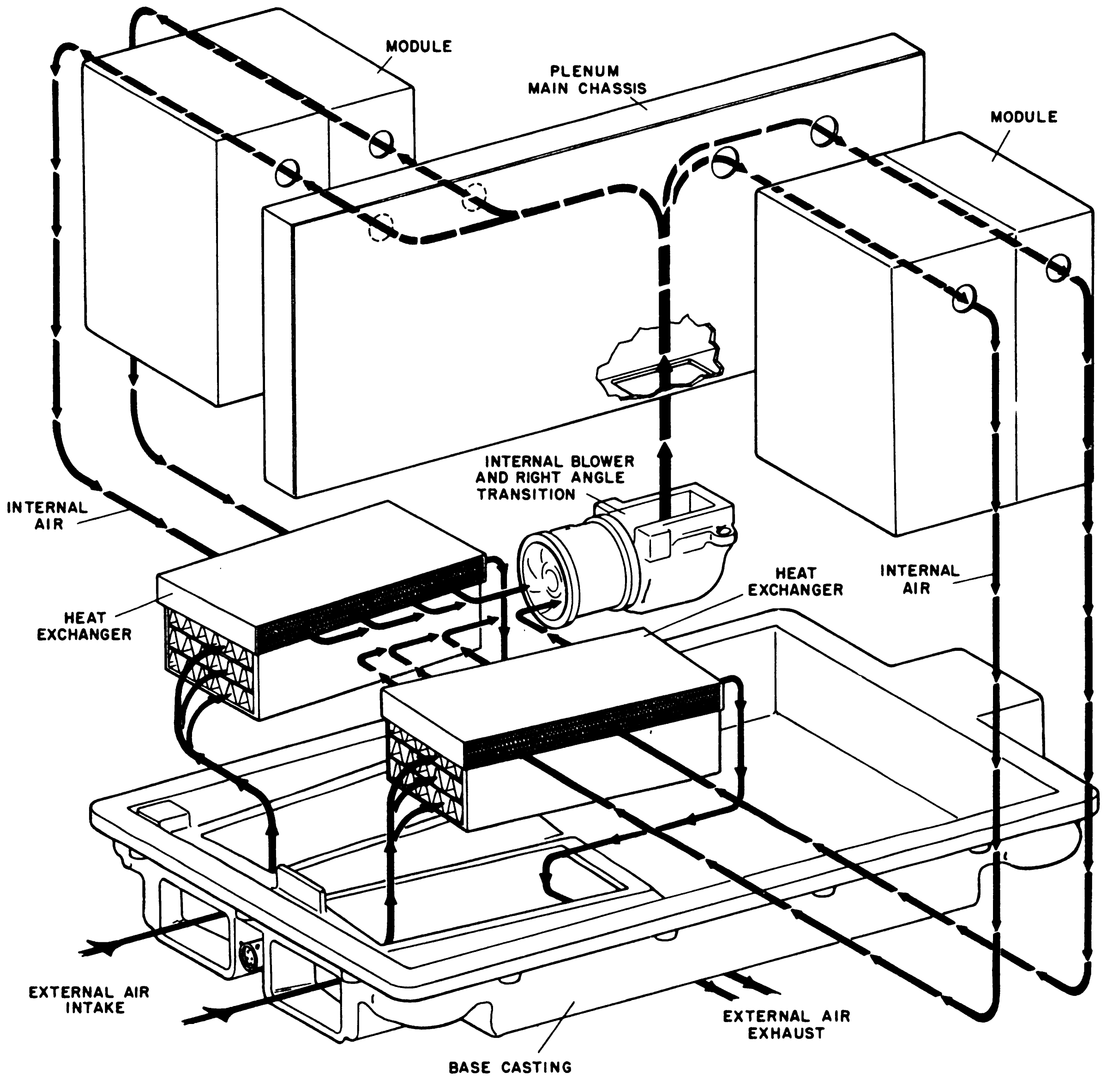

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Figure 16-18.—Cooling airflow diagram.

the power on-off and the selection of the associated radio equipment. Frequency adjustments for preselected channels are made by lowering a small panel at the bottom of the front panel.

Principles of Operation

Radio Receiver-Transmitter RT-649/ARC-88 is a remotely controlled receiver and transmitter which makes use of the double-conversion superheterodyne principle. Two sources of injection frequencies are heterodyned with the signal input during receiving operation, or heterodyned with a developed carrier during transmitting operation, to produce the desired intermediate frequencies. (See fig. 16-19.)

The higher injection frequencies are developed in the spectrum generator module and are in the 200 MHz to 370 MHz range. The fundamental signals are produced by a crystal oscillator, fed through a frequency multiplier, amplified, and then applied to the first receiver mixer or the second transmitter mixer stage.

The lower injection frequencies in the 21.85 MHz to 31.75 MHz range are produced in the oscillator stages of the 20-30 MHz IF am-

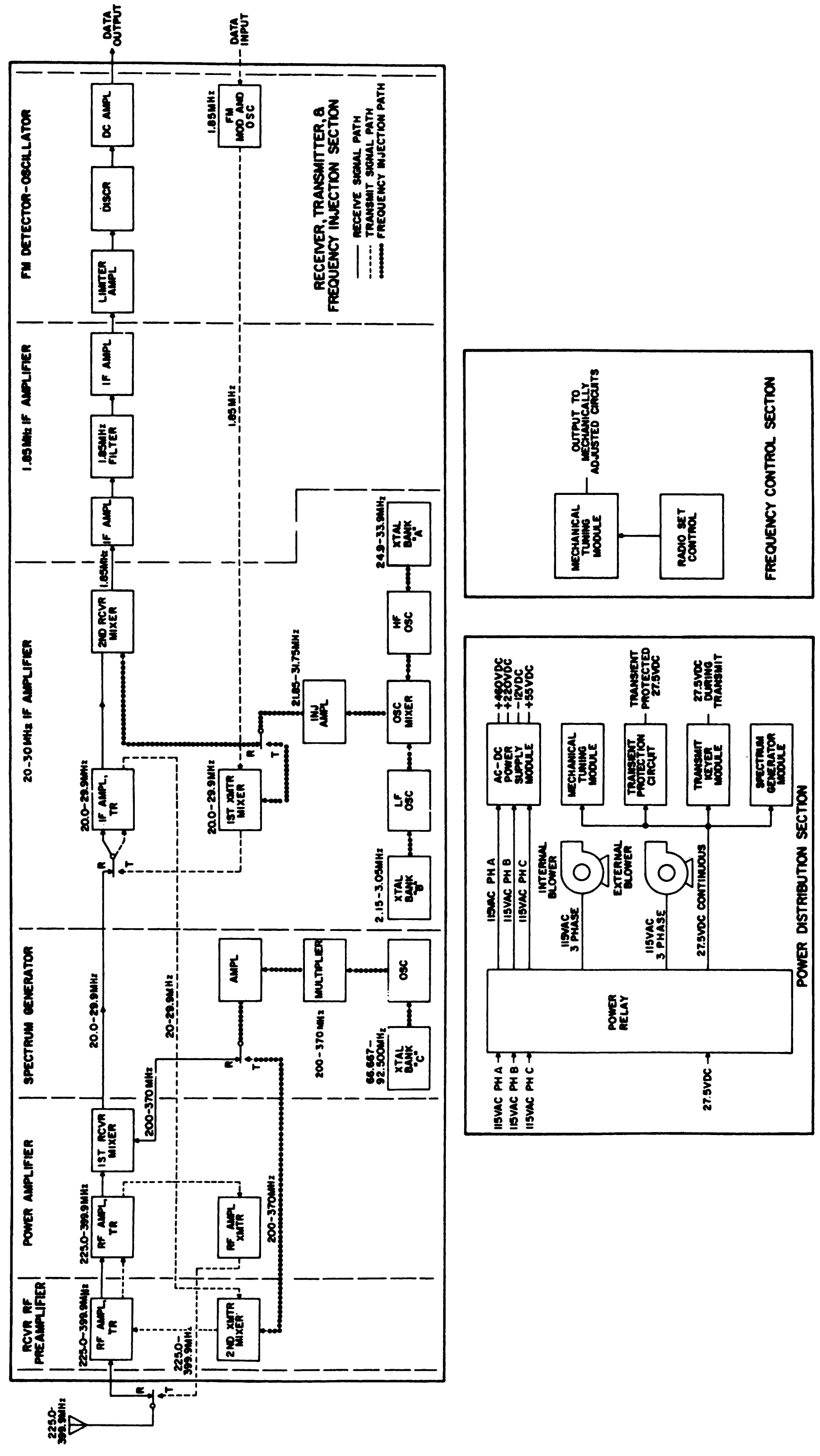

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Figure 16-19.—AN/ARC-88, simplified block diagram.

plifier module by mixing the output of two crystal oscillators. One of these oscillators provides an output in the range of 24.9 MHz to 33.9 MHz and the other 2.15 MHz to 3.05 MHz. The heterodyne difference frequency in the 21.85 MHz to 31.75 MHz range is amplified and applied to the second receiver mixer or to the first transmitter mixer stages. Relays accomplish circuit switchover from receiver to transmit operation.

The crystal-controlled frequency generation and injection systems are ganged mechanically to the tuning mechanism of the RT unit. All tuning or channeling is accomplished by the mechanical tuning module, in response to Radio Set Control C-2736A/AR.

The received signal, consisting of a frequency shift keyed carrier within the range of 225.0 MHz to 399.9 MHz, is fed from the antenna through an antenna relay into the amplifier circuits of the receiver RF preamplifier module, and applied to an RF amplifier circuit of the power amplifier module. In the power amplifier module, the received signal is further amplified and mixed with the 200 MHz to 270 MHz injection voltage output of the spectrum generator module. The resultant 20.0 MHz to 29.9 MHz first intermediate frequency is applied to the 20-30 MHz IF amplifier module where it is mixed with the 21.85 MHz to 31.75 MHz output from the two crystal oscillators within the 20-30 MHz IF amplifier module. The heterodyned difference between the first intermediate frequency and the output from the 20-30 MHz IF amplifier module crystal oscillators is mixed in the 20-30 MHz IF amplifier module to produce the 1.85 MHz second intermediate frequency. This output is fed through a 1.85 MHz filter, four stages of IF amplification, and two limiter stages to a discriminator. After demodulation, the data signal is amplified in two d-c amplifier stages and fed to the associated data equipment.

The operation of transfer relays and electron tube switching, from receive to transmit or from transmit to receive operation, is accomplished by the transmit keyer module in response to data input signals from the associated data equipment.

During transmission, the initial excitation is obtained from a frequency modulator and oscillator in the FM detector-oscillator module which operates at a center frequency of 1.85 MHz and is frequency modulated with the data information furnished from the associated data equipment. The 1.85 MHz frequency-modulated signal is mixed with the 21.85 MHz to 31.75 MHz injection signal from the two crystal oscillators within the 20-30 MHz IF amplifier module. The heterodyned difference between the 1.85 MHz signal and the oscillator injection signal produces the 20 MHz to 29.9 MHz intermediate frequency. The 20 MHz to 29.9 MHz intermediate frequency is fed through two stages of amplification in the 20-30 MHz IF amplifier module and mixed in the second transmitter mixer stage of the receiver RF preamplifier module with the 200 MHz to 370 MHz injection output from the spectrum generator module. The resultant carrier frequency of 225.0 MHz to 399.9 MHz is then fed through two stages of amplification in the receiver RF amplifier module, three stages of amplification in the power amplifier module and applied to the antenna.

Channel Selection

The set contains provisions for either automatic or manual selection of the operating frequency channel. Selections of channeling mode and operating frequency are made at the control unit. Actual tuning is accomplished by mechanical linkages in the mechanical tuning module.

Both automatic and manual channel selection are accomplished by tuning the tank circuits of the receiver RF preamplifier, power amplifier, 20-30 MHz IF amplifier, and spectrum generator modules for reception or transmission on the selected frequency.

In regard to channel selection, the terms automatic and manual are used to differentiate between the selection of one of 19 preset channels by rotating the channel selector switch and the selection of one of 1750 frequency channels by individual setting of the manual frequency controls. In either case, the actual mechanical and electrical tuning operations within the equipment are fully automatic.

Selection of any frequency is initiated when the operator rotates the decade selector to the desired frequency. By rotating a particular decade selector, the switch circuit that corresponds to the new frequency setting is grounded. By grounding the switch circuit, the positioning system of the mechanical tuning module is energized and produces a synchronized rotation of the gear train in the prescribed direction by a predetermined amount. The motion imparted to the gear train automatically adjusts the module tuned circuits for operation of the equipment on a selected frequency.

A simplified positioning system to illustrate the principle is shown in figure 16-20. The selector switch (remote control switch) chooses the operating frequency, and the seeking switch determines the angular position to which the drive motor rotates the shaft for a specific selected frequency. As shown, the equipment is at rest with the selector switch and the seeking switch at position 1. When the switches are at the corresponding position, no contact of the seeking switch is grounded through the selector switch; the electrical circuit of the drive motor is broken by the open motor control contacts of the deenergized relay.

The drive motor, which has driven the seeking switch to rest at position 1, has also driven the module tank circuits to the selected frequency in the same angular rotation.

Assume the selector switch is rotated so that the tab of the selector contacts the terminal at position 2. A closed path to ground then is completed from the +27.5-volt supply through the relay coil, the common contact and contact 2 of the seeking switch, through contact 2 of the selector switch, and to ground through the common contact of the selector switch. Relay K1 is energized and closes the motor control contacts; the drive motor then rotates in the predetermined direction. The seeking switch, which is geared to the drive motor, is driven until the cutout of the seeking switch is adjacent to position 2. At this position, the 27.5-volt path is opened, the relay releases, the motor stops, and the system comes to rest. Since the seeking switch and the tuned circuits are gear-driven by the motor, the tuned circuits are driven through the required angular displacement, which is proportional to

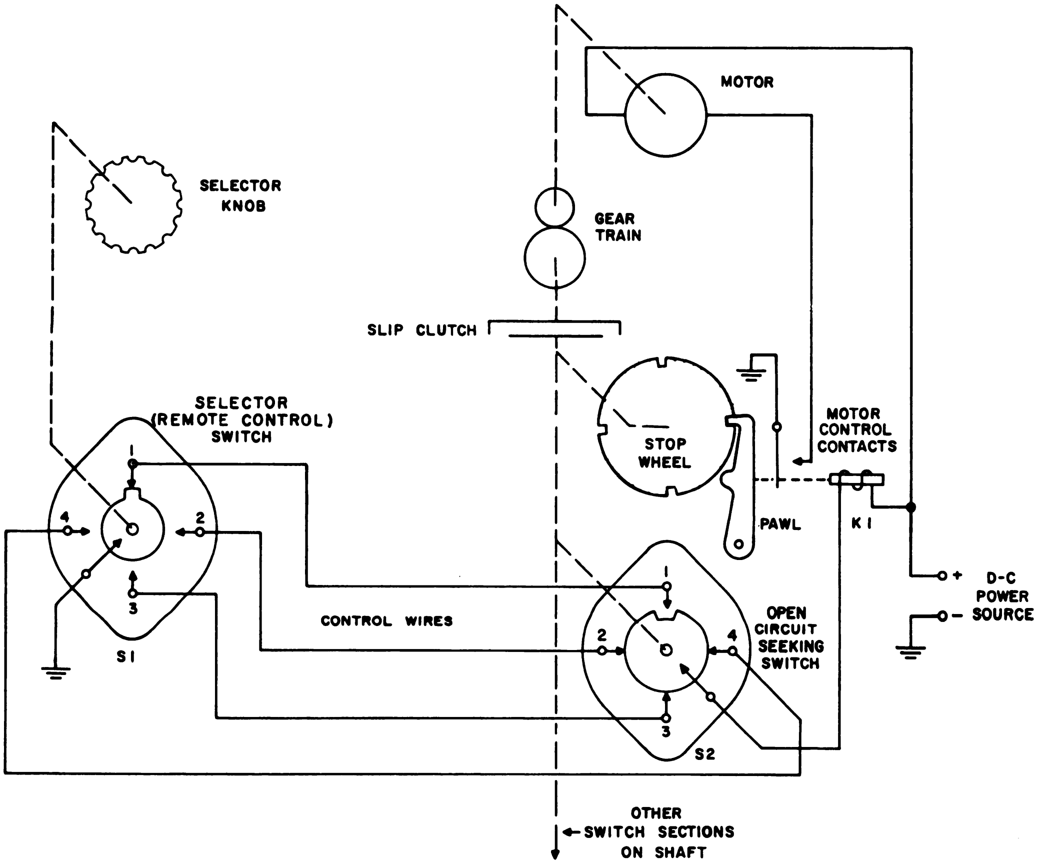

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Figure 16-20.–Automatic positioning, functional diagram.

the seeking switch travel from position 1 to position 2.

As illustrated in figure 16-20, the switch arrangement includes a notched stop wheel and pawl that accurately positions the seeking switch as soon as the drive motor is deenergized, and a clutch that decouples the switches from the drive motor and gear train when the final position is reached. Although not shown in figure 16-20, the clutch permits a single motor to drive several seeking switch shafts.

Assume the selector switch is rotated so that the circuit having the increments of the selected frequency is grounded. A complete path to ground is provided from the 27.5-volt supply through the relay coil, the seeking switch, the applicable control wire, and the selector switch. The actuated relay withdraws the pawl from the notch along the periphery of the stop wheel and energizes the drive motor through the closed motor control contacts of the relay.

The subsequent rotation of the drive motor, which is in a predetermined direction, drives the gear train, clutch, stop wheel, and seeking switch. The motor rotation is continuous until the motor (and tuning gear train) has rotated through the required tuning angle; at this point, the corresponding contact of the seeking switch is open, breaking the path to ground from the 27.5-volt supply. The relay releases, permitting the pawl to engage a stop wheel notch at which time the motor control contacts open. The subsequent loss of stop wheel motion brakes the seeking switch and shaft. The kinetic energy of the drive motor (which persists after the removal of the drive motor source power) is dissipated in the gear train and clutch. At rest, the seeking switch and shaft are in a position synchronous with the position of the selector switch.

In actual practice, to insure proper positioning of the stop wheel, the seeking switch opens the relay circuit shortly before the stop wheel reaches the notch to be engaged by the pawl. The relay motor control contacts are operated mechanically by the pawl arm so the contacts remain closed until the pawl drops into the prescribed notch.

The channel selector circuits of Radio Receiver-Transmitter RT-649/ARC-88 and Radio Set Control C-2736A/AR are more complex but use the principles of the single selector-seeking system shown in figure 16-20. The actual system, however, employs three selector-seeking switch groups which are driven by a single motor. (Refer to figure 16-21.) Each of the three groups has individual switch connections, relay, pawl, stop wheel, and relay motor contacts.

The seeking switches are driven by the motor through three separate friction type slip clutches, one of which is attached to each of the three primary shafts. When a pawl is not engaged in a stop wheel notch, the tension in the clutch spring is sufficient to allow the motor to turn the seeking switch shaft. When the stop wheel is held by the pawl, the motor side of the clutch can rotate while the seeking switch side of the clutch remains motionless. Several seeking switch shafts thus may be independently positioned by a single drive motor and gear system.

The channel selector system is, essentially, a three-section decade system that allows two alternative methods of inserting a different frequency setting: automatic, wherein any one of 19 preset channels may be selected by the channel selector switch, and manual, wherein any one of 1750 channels may be selected by means of four separate decade selectors, each of which must be set up individually for the frequency increment within its range. The two methods may both be subdivided into four parts consisting of the 200 MHz to 300 MHz, 10 MHz, 1.0 MHz, and 0.1 MHz decade selectors.

AUTOMATIC COMMUNICATIONS RELAY AN/ARC-52

Radio Set AN/ARC-52 provides two-way, amplitude-modulated radiotelephone communication (A-3) between aircraft in flight, aircraft and shore, and aircraft and ship. It is capable of transmitting and receiving on any one of 1750 manually selected frequency channels, spaced at 100 kHz intervals, in the band of 225.0 MHz to 399.9 MHz. It also permits the selection of any one of 18 preset channels within the specified frequency range, or the guard channel, which may be monitored on the predetermined frequency of 243.0 MHz. Auto relay is an alternate mode of operation which makes possible automatic communication relay operation.

Two receiver-transmitter units operate identically and are completely interchangeable providing correct input power is present. The only difference between the two receiver-transmitters is the input power required. Receiver Transmitter RT-332/ARC-52 requires both a-c and d-c power, while Receiver-Transmitter RT-424/ARC-52X requires only d-c power.

Unless otherwise noted, Auto Relay Control C-2791/ARC may be used interchangeably where Radio Set Control C-1607/ARC-52 is referenced, and Receiver-Transmitter RT-424/ARC-52X is used interchangeably where Receiver-Transmitter RT-332/ARC-52 is referenced.

Automatic direction finding (ADF) operation is provided by the AN/ARC-52 when used in conjunction with Direction Finder Group AN/ARA-25. During ADF operation, the AN/ARC-52 receives RF signals from a direction finding antenna and delivers appropriate signal components to the direction finder amplifying and indicating equipment.

Emergency or direction finding (DF) operation is provided by a self-generated tone that occurs between 920 and 1120 hertz. The tone modulation (A-2) is a continuous signal, the interception of which may be used to locate the sending apparatus.

Automatic relay operation may be provided by two Radio Sets AN/ARC-52 connected in tandem between two prime stations. However, to provide this operation Auto Relay Control C-2791/ARC must be substituted for Radio Set Control C-1607/ARC-52 in at least one of the Radio Sets AN/ARC-52. When connected in this manner, an incoming signal received on one radio set is retransmitted automatically from the second radio set but on an alternate frequency. The range of the prime stations is thus extended since the automatic relay station effectively increases the line of sight between the two prime stations.

The intercom provision is an optional facility which can be connected for use as a

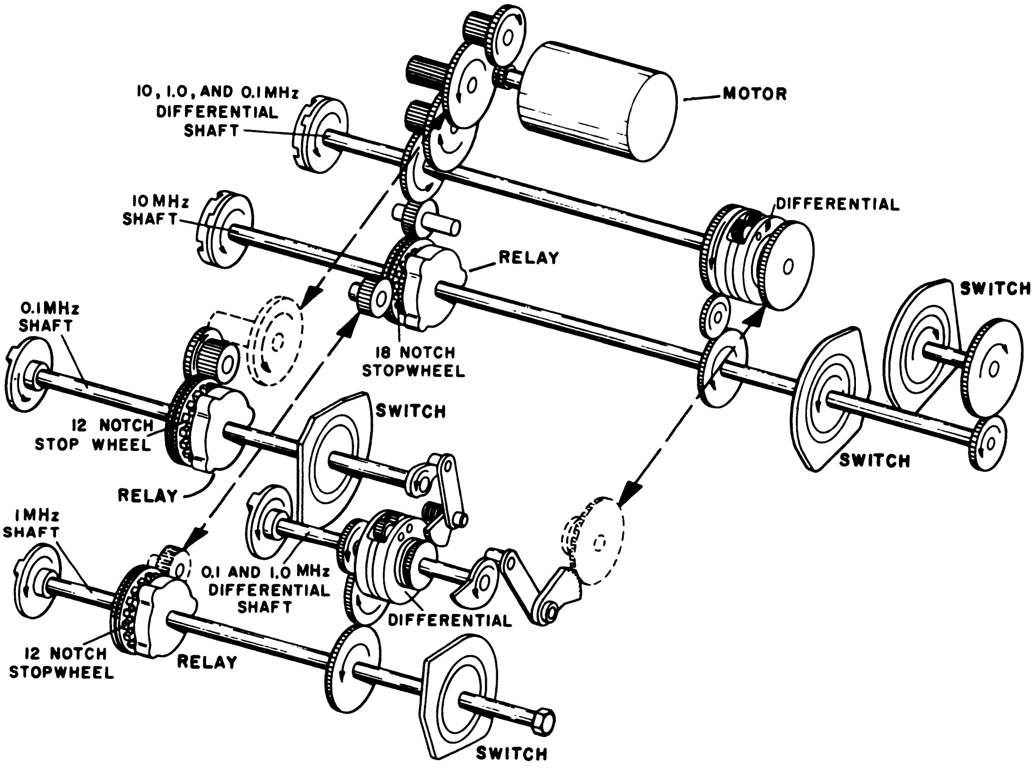

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Figure 16-21.–Mechanical tuning linkages.

backup in case the separate intercom amplifier system of the aircraft fails. When operated in this mode, the transmit function is limited to the pilot only, unless special connections are included at the time of intercom installation.

Optimum performance may be attained through the use of either a carbon or a dynamic microphone, which provides a high degree of flexibility. A change of connections within the RT unit is required when a change from a carbon type microphone to a dynamic type microphone (and vice verse) is made.

The RT unit may be installed anywhere within the aircraft through Mounting MT-1477/ARC-52. Since installation is usually external to the pressurized aircraft cabin, the RT unit case has been pressurized. The pressurized case and relatively inaccessible location prohibits the replacement or repair of equipment parts while in flight. The control unit does not require a pressurized case.

RT-332/ARC-52 Unit

The RT-332/ARC-52 consists of a pressurized aluminum case, a main chassis, and 13 plug-in unit subassemblies (modules). The main chassis with mounted subassemblies, is enclosed in a double-walled, pressurized aluminum case which functions as a heat exchanger between the outside air and the air within the case. Air is forced between the walls of the case by a dual blower mounted on the front panel of the main chassis. The air is expelled through vents in the top of the case, thus dissipating the heat absorbed by the inner walls of the case. An axial-flow blower and a blower mounted on the a-c power unit circulate the air inside the case.

The modules, each of which is a functional entity, are comparatively accessible when the case is removed, so that module replacement may be used as an initial troubleshooting procedure. The mounting base for the modules is the main chassis, which provides the interunit electrical connections, plugs, jacks, and coaxial cables. The modules may be removed from the top of the main chassis by loosening the captive screws from the underside of the main chassis.

The front panel of the RT-332/ARC-52 contains the external blower and the antenna input jack. Headset and microphone jacks, test jacks, and sensitivity controls are located on the main chassis right-hand gusset plate. All jacks and controls on the gusset plate provide local maintenance facilities to the AN/ARC-52 repairman.

RT-424/ARC-52X Unit

The RT-424/ARC-52X is identical to the RT-332/ARC-52 except it contains only 12 plug-in unit subassemblies. The a-c power unit and rectifier unit used in the RT-332/ARC-52 are removed, and a new dynamotor power supply unit is installed in its place. Circulating air is provided by the internal blower motor of the dynamotor, and by an external d-c blower motor.

Radio Set Control C-1607/ARC-52

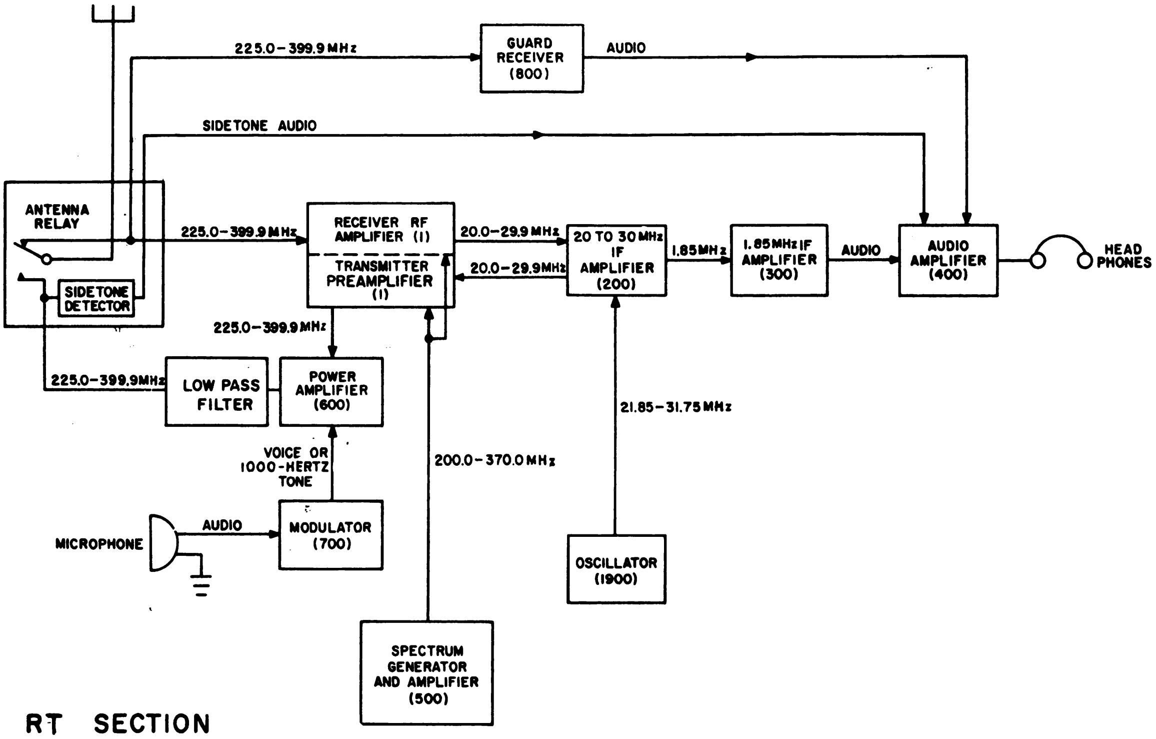
The C-1607/ARC-52 permits remote control of the RT-332/ARC-52 operation. These controls permit the selection of operational mode, volume control, frequency channel selection (channeling), and the means to set up and record the preset frequency channels.

Auto Relay Control C-2791/ARC

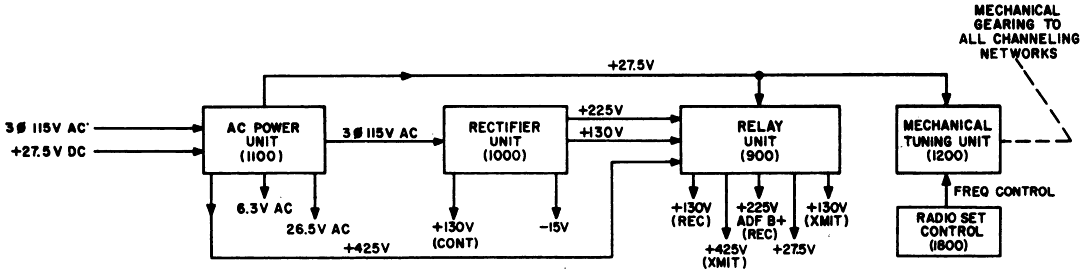
The C-2791/ARC performs all the functions of Radio Set Control C-1607/ARC-52 and additionally provides automatic relay (back-to-back) operation of two Radio Sets AN/ARC-52. The only visual difference between the radio set control and the auto relay control is the addition of an REL position to the function switch. By the addition of internal relays and the other component parts, the C-2791/ARC can place in operation two receiver-transmitters. Reception of a signal on the frequency of one receiver-transmitter will result in retransmission of the signal on the frequency of the other.

Principles of Operation

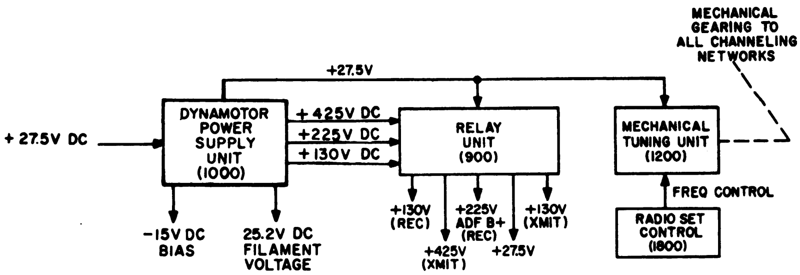
Radio Set AN/ARC-52 (fig. 16-22) is a remotely controlled transmitter and receiver unit equipped with all necessary control and mounting accessories. The transmitting and receiving components operate bilaterally; during reception the signal path is in one direction,



(A) RT SECTION



(B) POWER SECTION, RT-332/ARC-52



(C) POWER SECTION, RT-424/ARC-52X

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Figure 16-22.–AN/ARC-52 RT unit, block diagram.

during transmission the signal path is in the reverse direction.

The AN/ARC-52 has the greater sensitivity and the increased selectivity normally associated with double-conversion superheterodyne circuits. That is, an input signal is mixed with two separate but successive injection frequencies to obtain the desired intermediate frequency. Conversely, during transmission a basic frequency is mixed with the two injection frequencies to provide a carrier, the frequency of which is within the required range.

The received signal, which occurs in the 225.0 MHz to 399.9 MHz frequency range is applied to the RF amplifier and transmitter preamplifier module, where it is mixed with the 200 MHz to 370 MHz injection voltage output of the spectrum generator and amplifier module. The resultant 20.0 MHz to 29.9 MHz intermediate frequency is applied to the 20 MHz to 30 MHz IF amplifier module where it is mixed with the 21.85 MHz to 31.75 MHz injection voltage output of the oscillator module. The resultant 1.85 MHz intermediate frequency is filtered, amplified, and detected in the 1.85 MHz IF amplifier module and is then applied through the audio amplifier module to the headset.

The transmitter carrier is initiated within the oscillator module. The 21.85 MHz to 31.75 MHz output of the oscillator module is mixed with the 1.85 MHz signal in the 20 MHz to 30 MHz IF amplifier to produce a frequency of 20.0 MHz to 29.9 MHz frequency is applied to the RF amplifier and transmitter preamplifier module simultaneously with the 200 MHz to 370 MHz injection output of the spectrum generator and amplifier module. The resultant mixed carrier frequency of 225.0 MHz to 399.9 MHz is amplified and fed to the power amplifier module where it is modulated by the audio signals applied via the microphone and modulator module. The power amplifier module output, which passes through a 400 MHz low pass filter and terminates at the antenna, is a modulated carrier within the 225.0 MHz to 399.9 MHz frequency range. The modulated carrier is sampled by the sidetone detector of the antenna relay and applied to the audio amplifier module. This sidetone audio permits the operator to monitor the transmitted signal.

The guard receiver module is a single-frequency receiver which normally operates on a 243.0 MHz input frequency. The guard circuit is a double-conversion, superheterodyne type similar to the main receiver. Both receivers, however, work into a common audio output circuit.

The crystal-controlled injection systems, which are the sources of the beat frequencies, are ganged mechanically to the tuning mechanism of the AN/ARC-52 so that the selection of any frequency channels results in the development of a 20.0 MHz to 29.9 MHz and a 1.85 MHz intermediate frequency. All tuning, or channeling, is operated through the mechanical tuning unit module, the control of which is maintained at Radio Set Control C-1607/ARC-52.

The a-c power unit (RT-332/ARC-52 only, fig. 16-22 (B)) receives voltages from the 3-phase, 115-volt a-c and the 27.5-volt d-c power sources and distributes them to the required modules. The a-c voltage is applied to the rectifier unit, and the d-c voltage is applied to the relay unit and the mechanical tuning unit. In addition, the a-c power unit supplies a rectified output of 425 volts d.c. to the relay unit, and filament supplies of 6.3 volts a.c. and 26.5 volts a.c. to the appropriate filament distribution points.

The rectifier unit (RT-332/ARC-52 only) receives 115 volts a.c. from the a-c power unit and provides plate and bias voltages of +130 volts, +225 volts, and -15 volts d.c. The relay unit controls the transition between the transmit and receive function which, in turn, are controlled by the microphone press-to-talk switch. It provides three power switching functions:

1. Disable, wherein channeling will cause the AN/ARC-52 to revert to the receive function and any received audio signal is grounded.
2. Guard, wherein plate voltage is controlled for guard receiver operation.
3. Tone, wherein a continuous homing signal, 1000-Hz tone, is transmitted.

The relay unit provides selective switching of positive d-c voltages of 27.5, 130, 225, and 425 volts.

The dynamotor power supply unit (RT-424/ARC-52X only) receives 27.5 volts d.c. from an external power source and distributes this voltage to internal circuits. The same voltage also excites a dynamotor to produce d-c voltages of +425 and +130. From these voltages, additional d-c voltages of +225 (regulated) and -15 are developed. All d-c output voltages from the dynamotor power supply unit are applied, either directly or through the relay unit, to the plate, screen, and grid circuits in the receiver-transmitter.

A mechanical tuning unit controls the frequency selection of the equipment and, in turn, is remotely controlled from Radio Set Control C-1607/ARC-52. It operates in a manner similar to that on the AN/ARC-88.

TRANSCEIVER ALINEMENT AND TRACKING

A transceiver is a self-contained transmitter and receiver which share common circuits. The transmitter and receiver both operate on the same frequency, and the microphone switch determines when there is an output from the transmitter. In the absence of transmission, the receiver is sensitive to incoming signals.

Some of the common circuits are the antenna, master oscillator, and RF and AF amplifiers. Advantages of these common circuits are the overall reduction of the size and weight, and the lower power demand on the aircraft system.

Since there are circuits common to both the transmitter and the receiver, alinement and tracking are unique problems of the transceiver. Alinement is the adjustment of circuits to specific frequencies, and tracking is maintaining a constant frequency relationship between two or more circuits.

In order to aline and track common circuits in a transceiver, it is necessary to refer to the Service Instructions Manual for the particular equipment being used. This is because the circuits common to both the transmitter and receiver will vary from equipment to equipment; for example, between the ARC-44, ARC-52, ARC-88, and the ARC-94.

INTERCOMMUNICATION SYSTEMS

All aircraft intercommunication systems perform essentially the same basic functions. They deliver audio to one or more selected stations on board the aircraft to permit crewmembers to speak to each other. They also provide control of the communication facilities so that various members of the crew may receive incoming radio messages or initiate messages with the aircraft transmitters. It is also often necessary that the intercommunication system contain facilities for operating recording equipment so that permanent records may be made of the various receptions and transmissions occurring during flight.

It is not possible in the limits of the present discussion to describe all types of intercommunication systems installed in naval aircraft. A few examples are given which show characteristics common to most installations, while at the same time presenting characteristics which represent the newer developments in this type of equipment.

INTERCOMMUNICATION SET AN/AIC-14

The AN/AIC-14 ICS is an airborne internal communication system which integrates and coordinates all the audio facilities of the communication and other electronic equipment. The overall design is based on modular construction to provide a very high degree of versatility and reliability. Easily replaceable plug-in transistorized amplifier modules insure reliability under severe environmental conditions. A variety of individual component parts and subassemblies are available for use with and within the system, permitting adaptation of the basic system for use in many different types of installations having various audio requirements. Thus the basic system and its numerous variations provide for almost trouble-free service over prolonged operating periods.

The maximum capability for AIC-14 interphone installations in a single system permits operation of any combination of up to 30 individual stations without readjustment of the interphone volume control. Under maximum usage the overall output level from the control unit does not vary by more than 3 db. All signal inputs are isolated from each other by at least 50 db, thus minimizing the effect of a single station on the operation of the overall system.

In addition to the interphone stations which are normally manned during aircraft operations, auxiliary stations may be provided for use by ground personnel during maintanance, inspection, or servicing of the aircraft. Any combination of audio inputs (up to a total of 30) may be monitored without requiring adjustment of the volume control. Through operation of control switches, up to 11 outputs may be controlled.

The selection and monitoring of interphone and radio receiver signals, as well as the selection of transmitters to be keyed, is accomplished through selector switches and controls located on the front panels of the units to be controlled. The modes of operation (normal or auxiliary) and the energizing or deenergizing of interphone station microphones are controlled by operating appropriate switches on the front panel of the interphone control. The interphone control also permits the use of external keying switches.

To illustrate the flexibility and versatility of the AN/AIC-14 system, some of the various types of components and accessories are described briefly. The discussion is limited to the important features and peculiar applications of each item discussed. The list, although quite extensive, is far from a complete listing of items used in conjunction with the AN/AIC-14 Intercommunication Set.

Control Units

Control, Interphone C-2645A/(or C-2645B)/AIC-14 is the master control unit for the system, and is located at all manned interphone stations. Two transistorized plug-in amplifier modules (one isolation and one interphone) are included in each unit. The isolation amplifier provides the amplification and isolation necessary for all incoming audio (interphone and radio receiver). The interphone amplifier provides the amplification and isolation necessary for all outgoing audio (from the station's microphone). Each amplifier is capable of delivering a nominal output power of 300 milliwatts to the stations' earphones or to the interphone line.

The control unit also provides an alternate mode of operation for either or both amplifiers. If one amplifier becomes inoperative, its functions may be shifted to the other; if both the amplifiers become inoperative, they may be bypassed by switching to the EMERG position. In the emergency mode, incoming signals are supplied directly to the headset and outgoing signals are fed directly to the transmitter; no interphone communication is possible.

In almost all aircraft, additional control units are used to extend and expand the capacity of the ICS. A few such auxiliary control units are discussed briefly in the following paragraphs.

The C-2642/ or C-2642A/AIC-14 provides a means for selecting transmitter or interphone operation, interphone disconnect, and volume adjustment of incoming radio receiver signals. Any one of up to 11 transmitters can be selected.

The C-2643/AIC-14 is a selector panel for radio receivers and transmitters, permitting selection of any combination of two transmitters and four receivers. It incorporates isolation networks for all incoming signals.

The C-2644/AIC-14 incorporates facilities for selecting transmit or receive operation, a volume control for mixed radio receiver signals, and isolation for all incoming signals.

The C-2646/AIC-14 is an auxiliary control used primarily by maintenance personnel. It is located at auxiliary stations not normally manned during flight. It uses the common audio line for both incoming and outgoing interphone signals, and permits communication with any station which is connected to the common audio line.

The control contains a single amplifier. Incoming audio signals are isolated and amplified; in this case the amplifier acts as an isolation amplifier. When a push-to-talk circuit is energized, the microphone input is amplified and fed to the common line; the amplifier then switches to interphone operation.

The microphone and headset jacks can be used only with a 600-ohm headset and a carbon microphone with a nominal impedance of 100 ohms. When a dynamic microphone and low impedance headset are used, signal preamplification and transformer matching are required. This may be conveniently accomplished with the use of associated accessory cordsets discussed later in this chapter.

The mounting plate MT-2075/AIC-14 is used in conjunction with the C-2646. It includes a quick-dismounting feature provided by four slide fasteners which are secured by lockwire.

The C-2647/ or C-2647A/AIC-14 provides facilities for increasing the number of either receivers or interphone stations. It provides isolation for all signals. The function as interphone station selector or as receiver selector is determined by the position of an internal plug-in unit. This function is established at the time of installation, and is not normally changed thereafter.

When used as a receiver selector, any one or any combination of 12 receivers may be selected and isolated. When used as an interphone station selector, the unit selects and isolates any one or any combination of 12 signals. An alternate provision enables position 12 to be used either to select a specific station or as an "all-call" for up to 11 stations.

The C-2648/ or C-2648A/AIC-14 control permits selection of six additional receivers or interphone stations. In other respects it is similar to the C-2647.

Interconnection Box J-1013/AIC

This accessory enables the AN/AIC-14 to operate with either carbon or dynamic microphones and either high or low impedance headsets. The unit contains a 60-db transistorized preamplifier and two impedance matching transformers. The preamplifier and transformers may or may not be used, depending on the position of the connecting links in the box. A table illustrating the link settings for various types of microphones and headsets is located on the inside of the cover plate.

Microphones

A carbon microphone may be connected directly into the AN/AIC-14 Intercommunication Set, or it may be connected through a J-1013 interconnection box. If the J-1013 is used, the links must be set so as to bypass the microphone preamplifier. Dynamic microphones, if used, must be connected through the J-1013. The links must be set so that the 60-db gain of the microphone preamplifier is used.

The RS-38D-2 is a hand-held, high output (0.25-volt, rms), noise-canceling carbon microphone. Its termination (plug PJ-068) mates with the MIKE jack on the interphone control C-2646 or on any installation which accommodates conventional carbon microphones.

The M-3A/A is a high output (0.25-volt, rms), boom-mounted, noise-canceling carbon microphone. Its termination (PJ-292) is a two-prong plug which mates with the receptacle on the H-173/AIC headset and the CX-1301/AR cordset.

The ANB-M-C1 is a high output (0.25-volt, rms) carbon microphone normally used in oxygen masks. It terminates in the PJ-292 plug.

The M-92/U is a hand-held, noise-canceling, dynamic microphone with a built-in transistorized amplifier. In appearance and characteristics it is the equivalent of the RS-38D-2 carbon microphone, and may be used interchangeably with it. If a J-1013 is used, the link settings should bypass the preamplifier.

The M-96/A is a boom-mounted, noise-canceling, dynamic microphone similar in appearance to the M-3A/A carbon microphone and terminated in the same type (PJ-292) plug. In use, however, the two are not interchangeable. The M-96/A has a nominal output impedance of 7 ohms, and delivers an output voltage of 300 to 500 microvolts. The J-1013 must be used, and the microphone preamplifier and the appropriate impedance matching transformer must be connected by the changeable links.

The M-94/A is the dynamic microphone used in oxygen masks. In appearance it resembles the AMB–M-C1, but the two are not operationally interchangeable. In electrical characteristics and service limitations, the M-94/A resembles the M-96/A.

Earphones and Headsets

Several types of earphones and headsets are used with the AN/AIC-14 system. In actual practice the headsets may be so constructed that the earphones are either used separately (split-phone) or connected in parallel. They may have either a low or a high impedance.

Earphones H-87B/U are the dynamic type commonly used in helmets and headsets. The earphones have an impedance of 7 ohms as compared to the 600-ohm impedance of the ICS. The phones may be connected to a 25020 cordset which is terminated in a short plug. In this arrangement, an impedance matching transformer in the plug permits the H-87B/U to be inserted directly into the ICS control box. If connected through the J-1013, the links should bypass the impedance transformers.

By using the cordset CX-4832 the earphones are connected in parallel, offering a 7-ohm impedance. This combination requires use of the J-1013 and its impedance matching transformers.

The H-173/AIC headset is a lightweight unit which is designed for maximum wearing comfort. It contains the H-87B/U earphones and incorporates provisions for mounting boom microphones. The earpieces eliminate most of the surrounding noise. A quick-disconnect feature provides safety and ease of handling.

The H-3/ARR-3 is a dynamic headset with built-in impedance matching transformer, which adapts the 7-ohm phones to the 600-ohm system. This allows the headset to be directly inserted into the ICS. If connected through a J-1013, the impedance transformer must be bypassed.

Cordsets

Many types of cordsets are used with the AN/AIC-14. These cordsets are used for connecting the various types of microphones, headsets, and connection boxes within the system. Some include amplifiers and/or impedance transformers; others do not. The following paragraphs present a brief discussion of several of these cordsets.

The CX-1301/AR is a coiled cordset terminated on one end with a Junction Box J-193/AR and on the other end with a U61-U receptacle. The cordset is normally used with carbon microphones and high impedance headsets. If incompatible accessories are used, the J-193/AR is removed from its mounting and the CX-1301/AR is replaced by a J-1013. The mounting holes of both connecting boxes coincide.

The CX-4620/AR is a 75-foot, 5-conductor cable with an in-the-line switch containing a preamplifier, impedance transformer, and microphone keying switch. One end is terminated in a connector which mates with the J-1013 input connector. The other end mates with the H-173/AIC headset or a hardhat. This cordset may be used only with a dynamic microphone and a low impedance headset. However, the adjustable links in the J-1013 must be set to accommodate a carbon microphone and high impedance headset combination.

The CX-4621/AR is a 6-foot, 5-conductor, coiled cordset with terminations identical to those of the CX-4620/AR. Since it contains no preamplifier or impedance matching transformers, it may be used with either type headset and microphone. However, the links in the J-1013 must be connected accordingly.

The CX-4623/AR is a 9-foot, 5-conductor, coiled cordset. It includes an in-the-line switch similar to that in the CX-4620/AR, and is terminated in the same type connectors. It may be used only with a dynamic microphone and low impedance headset, but the J-1013 links must be set for the carbon microphone and high impedance headset combination.

The CX-4832/AR cordset is used to connect the earpieces of the H-87B/U in parallel, thus providing a low impedance output.

INTERCOMMUNICATION SET AN/AIC-15

The AN/AIC-15 system, marks a milestone in adaptation of transistor circuits to airborne applications in a form suitable for manufacture on a production basis. The total equipment consists of six types of major components; four types of station control boxes, a recorder control, and an interconnecting box.

Each of the control boxes with the exception of the recorder unit contains one microphone amplifier and one receiver amplifier. The type of box installed at a particular station of the aircraft is determined by the communication functions to be performed at that station. All boxes provide essentially the same intercom and receiver facilities. The system is not restricted to use with any specific radio receiver, recorder, or transmitter, but may be used with many different radio communication equipments.

System Operation

The major components of the AIC-15 are connected as shown in the block diagram in figure 16-23. The master unit (C-1908) contains controls for the complete set of radio and intercom facilities. The flight crew control (C-1910) provides the means for controlling two radio transmitters and for listening to two radio receivers. The recorder control (C-1912)

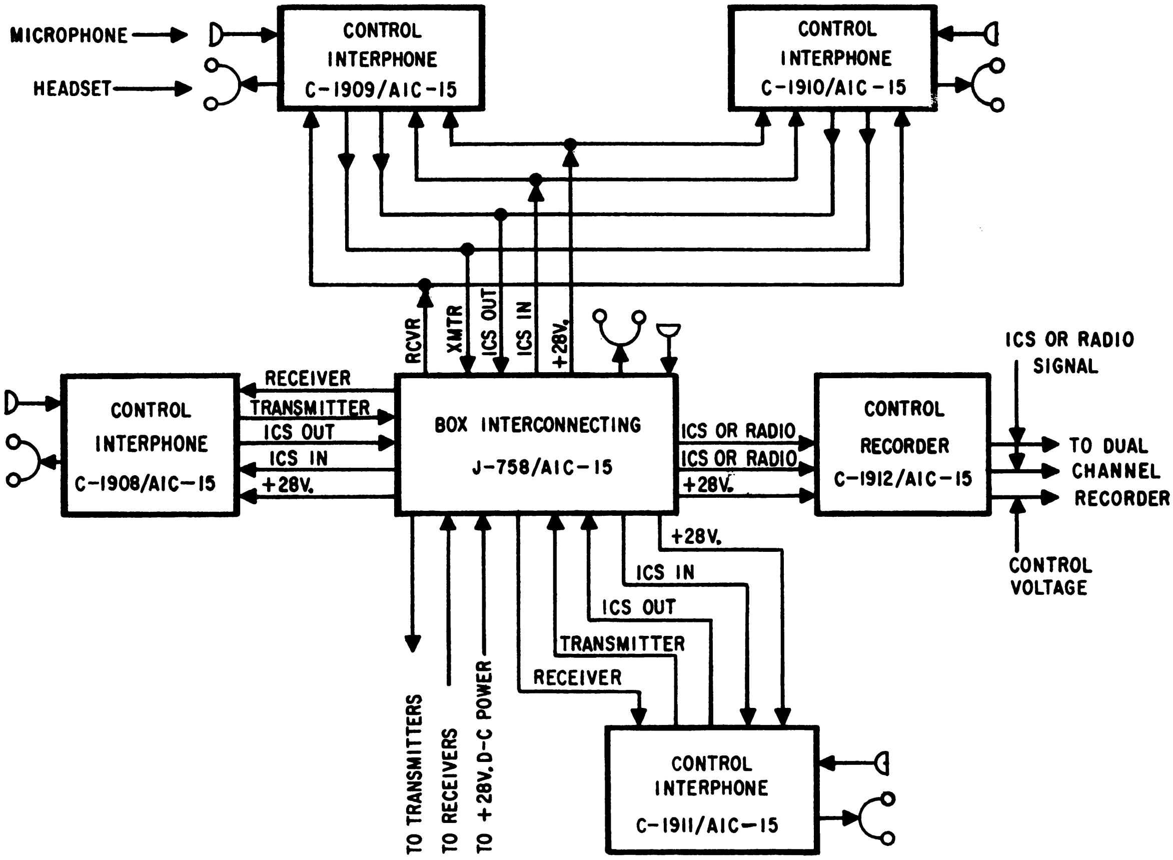

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Figure 16-23.–AN/AIC-15, system block diagram.

serves to route any of the signals present to a tape recorder so that it is possible to preserve the audio information exchanged during operation.

The central unit of the system, Interconnecting Box, J-758, connects incoming receiver signals to the various stations and also connects the control boxes to the aircraft transmitters for control of the latter during transmission. The interconnecting box can also be used as an additional control station since it contains jacks for a microphone and a headset.

Each of the station control boxes contains a microphone amplifier and a receiver amplifier and is therefore independent of any outside aid except d-c power. Thus, external cables are not required as would be the case with external amplifiers; and smaller wires are used due to lower power requirements. As a result, approximately 60 pounds of cable weight are eliminated in comparison with electron-tube counterparts of the system. An additional advantage of this compact method of amplifier packaging is increased flexibility, in that the number of control units can be decreased or increased without causing any deterioration in the performance of the system.

Because of the relatively low power consumption of the AIC-15, the system contains no on-off switch as such. The equipment is powered from a 28-volt, d-c supply and remains in the ON condition as long as the aircraft power system is in operation.

All audio switches are semiconductor devices. By placing an appropriate d-c bias on a particular interphone line, audio on that line can be routed into the control boxes attached to it. The audio switch for each interphone line is a germanium diode which acts as a short circuit to audio when a forward d-c bias is established. Conversely, the diode acts as an open circuit when back biased, thereby disconnecting the interphone line from the associated control boxes.

Under certain conditions it is necessary to use the intercom facilities while monitoring the output of the aircraft radio receivers. It is then desirable to reduce the volume of the receiver audio without eliminating it entirely. To accomplish this, the nonlinear impedance feature of a transistor is used to reduce the receiver audio that is present with the interphone signal at the receiver amplifier.

The radio volume is lowered by means of a d-c bias applied to the volume-reduction transistor, thereby changing the latter from a nonconductive to a conducting state. This, in turn, changes the impedance of the radio receiver audio input network in such a manner as to reduce the applied audio. As a result, the volume of the output from any radio receiver selected at a given control unit is reduced approximately 10 decibels with respect to the interphone level.

Interphone Circuits

A single interphone line is employed with each type of control station in the AIC-15 system. For example, the pilot, copilot, and radio operator are on a single interphone line and the remaining crew stations are on another. There is also a separate line to which all control stations are connected, which makes it possible to talk from any control box to all other stations in the system.

An emergency, or override, feature is provided by a separate line under control of the pilot, copilot, or radio operator. The emergency line can be switched on quickly and communication established with all crewmembers on the aircraft.

In addition to the interphone facilities, the AIC-15 circuits provide the means for listening to any combination of 9 radio receivers and for controlling the operation of any of 9 radio transmitters. The total number of stations may be as high as 13, a relatively large capability which is achieved with comparatively small requirements of space, weight, and power. The system is designed to operate on 10 watts of 28-volt, d-c power per control unit.

Transistor Amplifiers

As stated above, all the station control boxes (with the exception of the recorder unit) contain two compactly packaged transistor amplifiers—one for microphone amplification and the other for receiver audio amplification. Electrically, the two amplifiers are almost identical. The input circuit of the microphone amplifier is designed to work with a carbon microphone, whereas the input of the receiver amplifier is a conventional RC coupled, 600-ohms circuit. The output circuit in both is transformer coupled, consisting of an 800-ohm output from the microphone unit and a 600-ohm output from the receiver amplifier. Both are three-stage amplifiers with push-pull output and overall negative feedback. The receiver amplifier is illustrated in block diagram form in figure 16-24.

Both the microphone and receiver amplifiers employ silicon transistors. The input stage of the receiver unit is a type 904. The 951 transistor driver is transformer coupled to two 951 transistors which serve as a push-pull output stage. The first two stages are grounded emitter circuits with collector-to-base negative feedback and emitter resistance temperature stabilization. The output stage is a grounded base circuit biased for class B operation. An overall negative feedback loop of about 20 decibels is used to further stabilize the circuit operation.

The overall dimensions of each AIC-15 amplifier are 2.44 by 1.72 by 1.00 inches. The maximum power gain is approximately 35 decibels with a gain control provided to reduce the output signal to zero. The amplifiers are capable of an output of 300 milliwatts at less than 10 percent distortion and an output of 150 milliwats at less than 5 percent distortion. The frequency response is flat within ±2 decibels

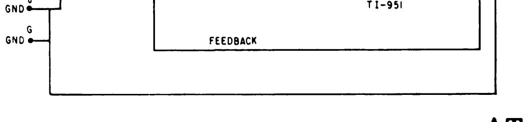

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Figure 16-24.—Block diagram of the transistorized receiver amplifier.

from 400 to 6,000 hertz. Satisfactory operation is maintained over the input B-plus voltage range of 22 to 30 volts d.c. About 80 milliamperes of current are required at the 28-volt B-plus level.

The amplifiers are potted to reduce vibration damage. For maintenance, the entire unit is replaced and no attempt is made to repair any component within the amplifiers. The weight of each amplifier is approximately 5 ounces, a very favorable figure when compared with a weight of 13 to 15 pounds in comparable units of older systems. Also with lower power requirements, an approximate reduction in load of 20 percent is realized.

Intercommunication Set AN/AIC-15 is of considerable importance for the Aviation Electronics Technician since it is one of the first completely transistorized electronic systems which have demonstrated capability of meeting all military requirements of its class and which has definite advantages when compared with hitherto standard designs. Among these are a relatively larger number of facilities controlled, less size and weight, lower power requirements, and greater reliability and flexibility as compared to its vacuum tube counterparts. The design specifications require at least 2,000 hours of satisfactory service without removal for bench servicing, a feature of essential importance for maintenance personnel. From the standpoint of operation, one of the outstanding features of the system is its clearness of transmission.

CHAPTER 17

AIRBORNE NAVIGATION EQUIPMENT

Airborne navigation equipment is a term embracing many systems and instruments. The technician is required to maintain and, in some instances, to operate various equipments. This chapter includes a discussion of the major navigational systems in present use, with reference to some typical equipments. These systems include electronic altimeters, radio range and related facilities, loran, radio direction finders, Doppler radar systems, and inertial navigation equipment.

ELECTRONIC ALTIMETERS

Electronic altimeters may be classified as radio or radar altimeters. They may operate on frequency modulation principles, or they may be pulsed. Electronic altimeters are frequently referred to as absolute altimeters, because they are used to measure height above the terrain rather than with respect to sea level.

This chapter contains a brief discussion of two of the later and more accurate altimeters in present use in the fleet.

ELECTRONIC ALTIMETER AN/APN-120

The Altimeter Set, Electronic, AN/APN-120 furnishes accurate radar altitude (above terrain) indications over all types of terrain and under any weather conditions. It operates on two ranges. The low range measures altitude up to 3,000 feet; the high range measures altitude from 500 feet to the maximum altitude of the aircraft. It is installed in the RA5C model aircraft and is an integral part of the weapons system. In addition to furnishing accurate altitude data for the pilot, the system also supplies data for correcting the barometric altitude calculated by the air data system. The final corrected barometric altitude information is used by the bomb directing set to compute weapon delivery patterns.

Characteristics

The altimeter system consists of a hybrid radar system. The low altitude subsystem consists of an amplitude-modulated, frequency-modulated, continuous-wave (AM-FM-CW) C-band radar set; the high altitude subsystem is of the pulsed type. Provisions are made for a low altitude warning light, which actuates at 400 feet altitude above terrain, and an indicator of signal reliability.

System functional loops represent the complete paths of signal flow within the system, subsystems, and circuits. These loops are not limited by their packaging or "black box" location.

Theory of Operation

For purposes of this discussion, the theory of operation for the AN/APN-120 is divided into a brief discussion of the functional loops. For detailed information regarding this equipment, refer to the applicable technical manuals. Figure 17-1 is a simplified block diagram of the altimeter, and should be referred to frequently in connection with this discussion.

LOW ALTITUDE MEASUREMENT LOOP.– The low altitude system transmits and receives an RF carrier in the C band of radar frequencies. The carrier is frequency modulated by 25 kHz, which is itself amplitude modulated by a 400 hertz voltage. (The 25 kHz modulation is required to develop frequencies representative of altitude.

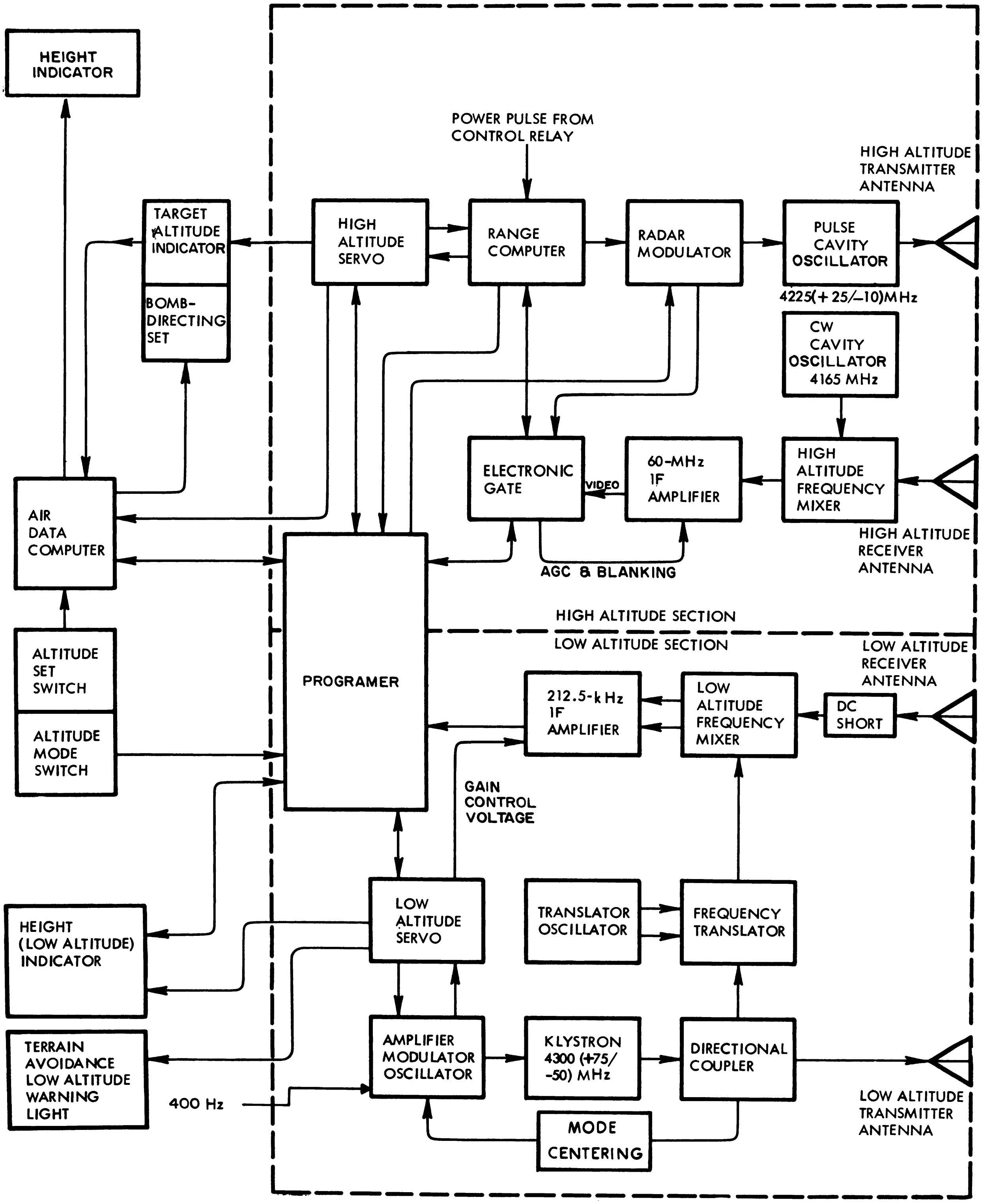


Figure 17-1.–Altimeter Set, Electronic, AN/APN-120, simplified block diagram.

The 400 Hz modulation is used to develop an error voltage when a difference exists between the altitude indicated by the returning RF energy and altitude indicated on the altitude readout. When an error voltage is developed, the servoloop corrects the indicator to agree with the radar return.)

In the transmitting portion of the low altitude loop, a 25 kHz signal is generated by an oscillator and modulated by a 400 Hz voltage from the aircraft supply. This complex signal is routed to the repeller of the klystron, thereby varying the klystron frequency of oscillation. The modulated RF is fed through a directional coupler to the low altitude transmitter antenna. A mode-centering circuit maintains the center frequency of the klystron at the center of its power mode.

The low altitude receiving antenna receives the signal reflected from the ground and feeds it to a frequency mixer. A sample of the transmitted signal is also routed (through a frequency translator) to the mixer. The input frequency of the translator is shifted so that the output is 262.5 kHz above the input frequency. The mixer output is a 262.5 kHz signal with sidebands corresponding to the frequency modulation on the received signal. Since the FM component of the received signal is 25 kHz, sidebands occur at multiples of 25 kHz away from the center frequency. This composite signal is then fed to the 212.5 kHz IF amplifier.

The maximum gain of the IF amplifier is governed by a gain control voltage from the servoloop, so that the gain is a function of altitude. The output of the amplifier programer unit is detected and filtered to produce an AM component and a d-c component. The d-c component provides the automatic gain control voltage and an indication of reliability. The AM component is compared with the aircraft 400 Hz reference to produce a correction signal for the height indicator.

HIGH ALTITUDE MEASUREMENT LOOP.—The transmitting portion of the high altitude system begins at the range computer. This stage initiates a trigger pulse at a stable repetition rate. The trigger pulse is used in the radar modulator to time and trigger the pulse forming circuits which pulse modulate the transmitter. The modulator also supplies a negative blanking voltage, synchronized by the same trigger, to the electronic gate.

The pulse cavity transmitter is caused to resonate by the modulator pulse, and supplies an RF pulse at approximately 4225 MHz to the antenna arrays. When the transmitted pulse is reflected from the terrain, a portion of the reflected wave is intercepted by the receiving antennas and becomes the received signal.

The received signal is fed into the high altitude frequency mixer. The CW cavity oscillator generates an a-c voltage at 4165 MHz for use as the local oscillator signal. In the mixer, the received signal (4225 MHz) beats with the local oscillator signal (4165 MHz) to produce an IF signal of 60 MHz.

In the IF amplifier, the gain is regulated by an AGC voltage. During transmit time, gain is reduced to almost zero by a blanking pulse from the electronic gate. This blanking pulse prevents self-triggering by the system's own transmitter. After amplification, the IF signal is detected to produce a video pulse.

The video pulse is gated, timed, and shaped in the programer unit to produce the altitude indication for comparison with the altitude reading on the indicator. Any difference between these values produces an error signal for the servoloop, which then corrects the reading of the instrument.

PROGRAMER.—The programer is common to both the low altitude and the high altitude systems. The programer is made up of circuits, which are partly interdependent in their operation, and performs the following functions which are not discussed in detail:

1. To process the d-c error signals (for low and high altitude range) to provide the required driving signal voltage for the respective servomotor.
2. To perform the required switching functions according to operational mode selection.
3. To provide automatic turn-on of the low altitude system when the altitude is less than 4,000 feet.
4. To provide time-sharing pulses which cause the two systems to alternate their "on" time whenever both systems are operating and the aircraft is at an altitude between 0 and 4,000 feet.

RADAR ALTIMETER AN/APN-141(V)

Electronic Altimeter Set AN/APN-141(V) is a C-band, pulsed, rangetracking radar that locks onto the leading edge of the echo pulse. It provides a continuous, highly accurate indication of absolute altitude from 10 to 5,000 feet above water or terrain. The accuracy and the reliability make possible extremely low altitude instrument flight missions in familiar or level territory. It also increases the safety of moderately low-level instrument flight missions into territory where the barometric pressure and terrain elevation data are unreliable or unknown.

The equipment consists of the radar transmitter-receiver unit, an RF switching unit, a height indicator, and two antennas.

Characteristics

Altitude information is continuously displayed, in feet of absolute altitude, on a panel-mounted indicator. This information is developed by radiating pulses of microwave energy downward and by monitoring the time required for the return of each pulse as an echo. Monitoring of pulse transit time is accomplished by means of a leading-edge electronic tracking loop which, in effect, locks onto the range of the water or terrain, and follows variations of clearance resulting from aircraft maneuvers or terrain elevation.

Leading-edge tracking provides for an indication of the nearest terrain under the aircraft, and not necessarily the terrain directly under it. Thus, the altimeter set will track a mountainside or a cliff ahead or to the side of the aircraft if this terrain is closer than the ground directly below the aircraft. This feature provides essential warning of rapidly decreasing absolute altitude on low-level missions.

The system has two altitude modes of operation—one for low altitudes and one for high altitudes. At low altitudes (0 to 195 feet ascending and 165 to 0 feet descending), a very narrow, low-powered transmitted pulse is utilized to obtain maximum range resolution. The low altitude pulse is also programed in width to provide the proper strength of the ground return signal with altitude variation. At altitudes above the ascending and descending upper altitude limits, a wider high-power transmitted pulse is utilized to obtain sufficient ground return energy for tracking.

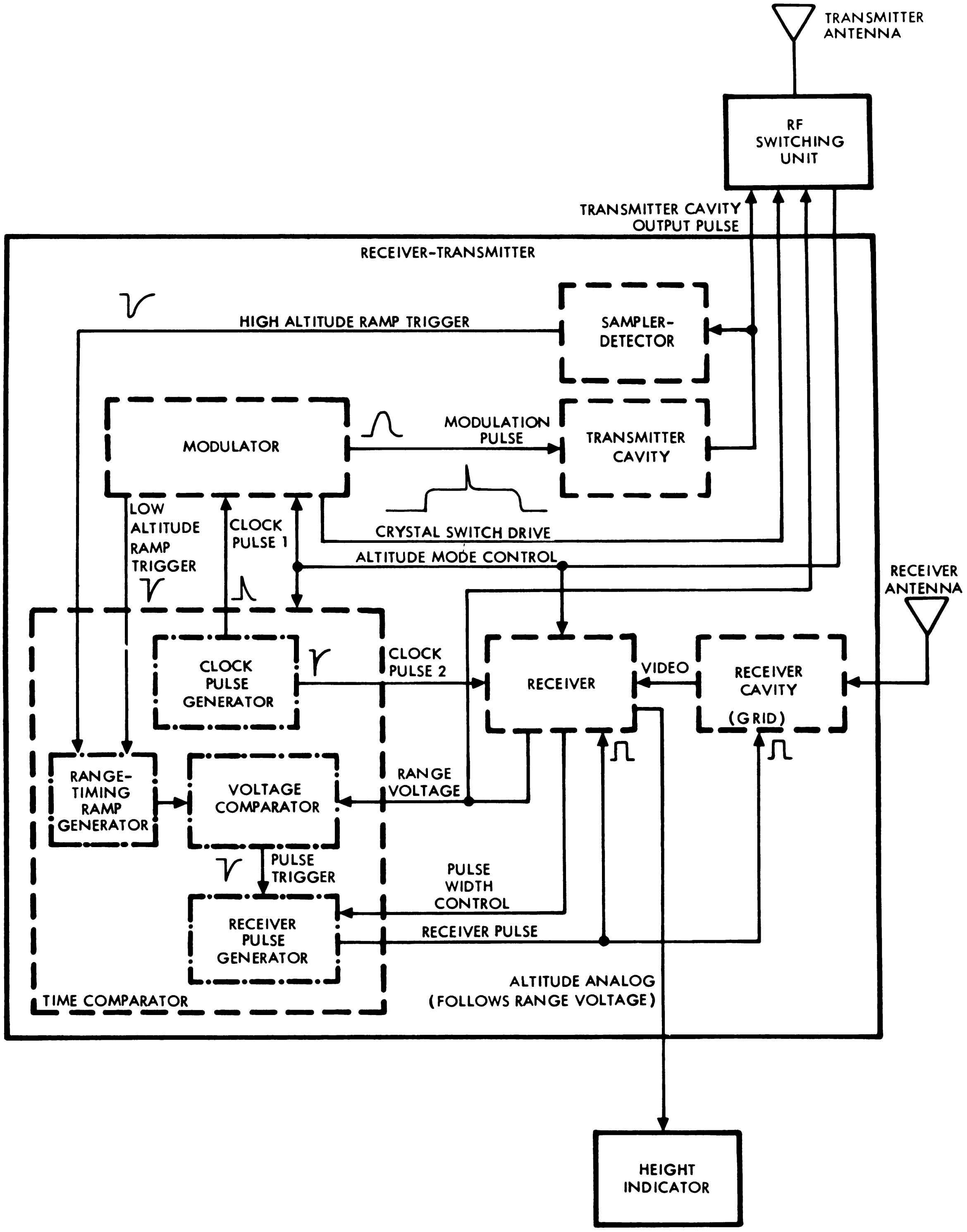
The altimeter system also has two ranging modes of operation—the search mode and the tracking mode. In the search mode, the system successively examines increments of range with each cycle of operation until the complete altitude range is searched for a ground return signal. When the altitude range is found, the system switches over to the tracking mode of operation. In the tracking mode, the system locks onto and tracks the leading edges of the ground return pulses and presents continuous altitude information.

Altitude information is obtained by measuring the time intervals from the instant that each pulse of RF energy leaves the transmitter until the leading edge of the ground return signal is detected in the receiver. The system converts this time interval information to a d-c range voltage which is offset in amplitude to form an altitude d-c voltage analog. This analog is fed to the height indicator which indicates altitude in feet proportional to the amplitude of the d-c voltage.

Theory of Operation

For the following general discussion of the theory of operation for Electronic Altimeter Set AN/APN-141(V), refer to figure 17-2. For more detailed information, refer to the applicable technical manuals.

TRANSMISSION.—Clock pulse 1 functions as the basic system timing trigger. This pulse is generated at a 3 kHz rate in the time comparator and is fed to the modulator where it triggers each transmission and cycle of operation. The modulator pulses the transmitter cavity and produces a crystal switch drive signal for gating the narrow RF pulse transmitted during low altitude operation. This gating is accomplished in the RF switching unit. The modulator also produces a range-timing ramp trigger for use in the time comparator during low altitude operation. The modulation pulse drives the transmitter cavity into oscillation, and the transmitter cavity energy is applied to the RF switching unit. A detected sample of the energy is taken from the cavity as a range-timing ramp trigger for use in the time comparator during high altitude operation.



AT.304

Figure 17-2.–Altimeter AN/APN-141(V), block diagram.

The RF switching unit is controlled by the d-c level of the range voltage input from the receiver, and performs two basic functions: gating of the peak power and width of the transmitted pulse, and switching of the potential on the altitude mode control line. During high altitude operation, the unit routes the full 1-kilowatt output of the transmitter cavity directly to the transmitter antenna and grounds the altitude mode control line. During low altitude operation, the unit attenuates, narrows, and programs the width of the cavity output pulse before application to the antenna. It also places a positive voltage on the altitude mode control line. The potential on the altitude mode control line enables or inhibits circuits in the modulator, time comparator, and receiver to provide the proper gating and timing in these three modules for each altitude mode.

RECEPTION.–The receiver antenna senses ground return signals and applies these pulses of RF energy to the receiver cavity. The receiver cavity is a superregenerative detector that generates an output only when pulsed by a positive grid signal. This signal is supplied by the receiver pulse generator in the time comparator. The cavity generates an output each time the receiver pulse is applied, but this output is of greater peak amplitude when ground return energy is present in the cavity than when this energy is absent.

The receiver pulse is generated twice during each operational cycle: First, for detecting the possible presence of ground return energy in the cavity, and later, when no ground return energy can be present for sampling the noise level in the cavity. Either type of cavity output is detected, and resulting high or low amplitude video signal is fed to the receiver. Simultaneous with cavity grid pulsation, the receiver pulse activates the receiver for two brief intervals in the operational cycle.

During the first interval, the receiver examines the video signal for the possible presence of a ground return signal. If the signal is absent, the receiver maintains the system in the search mode of operation. If the signal is present, the receiver switches the system over to the tracking mode.

During the second interval, the receiver samples the noise level in the cavity and utilizes the low amplitude video input to regulate the width of the receiver pulse for the automatic stabilization of receiver gain.

The receiver also utilizes its range voltage output to regulate the width of the receiver pulse for the adjustment of receiver sensitivity to ground return pulses with variations in altitude. Clock pulse 2, from the time comparator, triggers a circuit in the receiver that generates the receiver pulse width control signal.

SEARCH MODE OPERATION.–Figure 17-3 shows the idealized basic waveforms and time relationships involved in altitude acquisition and tracking. The (A) set of waveforms is common to both modes, and shows the basic timing and transmission references. The (B) set of waveforms applies to the search mode of operation, and the (C) and (D) sets apply to the tracking mode. The 3 kHz pulse repetition frequency of clock pulse 1 establishes a basic system period of approximately 333 microseconds for both the high and low altitude modes of operation. The signals and events required for altitude acquisition and tracking occur during the first 10-microseconds of this period over the interval of the range-timing ramp. (Since a radar time of 2 microseconds is approximately equivalent to an altitude of 1,000 feet, this first 10-microsecond timing interval corresponds to the 5,000 foot maximum altitude capability of the system.)

In the search mode, the range voltage from the receiver is a freerunning sweep of 2.5-second duration. The range-timing ramp and the range voltage sweep are both fed to a voltage comparator in the time comparator. When voltage coincidence of the ramp and range sweep occurs, the voltage comparator triggers the receiver pulse. The receiver pulse biases the receiver cavity into conduction and triggers a gate in the receiver that momentarily enables amplification and switching circuits to examine an increment of altitude. With no ground return signal present, the receiver cavity generates a small video signal that results from the buildup of the noise level in the conducting cavity.

The equal intervals in the first train of ground return signals shown in figure 17-3(B) represent the pulses present in the receiver cavity at a constant altitude. Over successive cycles of operation, the receiver pulse approaches the ground return pulse in time because of the successive delays in ramp and range sweep voltage coincidence. Throughout a complete 2.5 second range voltage sweep, the receiver pulse is generated approximately 7,500 times, and the altitude is effectively probed in increments of 1 foot. When the receiver pulse reaches the ground return signal in time, the video output from the receiver cavity builds up considerably above the previous levels attained by noise buildup, and switches the receiver from the search to the tracking mode of operation. The video input is then used as a range voltage amplitude control, resulting in the leveling of the range voltage at an amplitude equivalent to the time interval between the transmitted and ground return pulses.

TRACKING MODE OPERATION.—When switched over to the tracking mode, the receiver and the time comparator operate together to time the occurrence of the receiver pulse with a point on the slope of the leading edge of the ground return pulse. (See fig. 17-3(C).) With a constant altitude and a consequent steady range voltage, as well as fixed ground return period, this synchronism is merely coincidental. The automatically controlled synchronism required for following altitude changes is provided by a tracking servoloop consisting of the same basic components used in the search mode (switched to the tracking mode of operation).

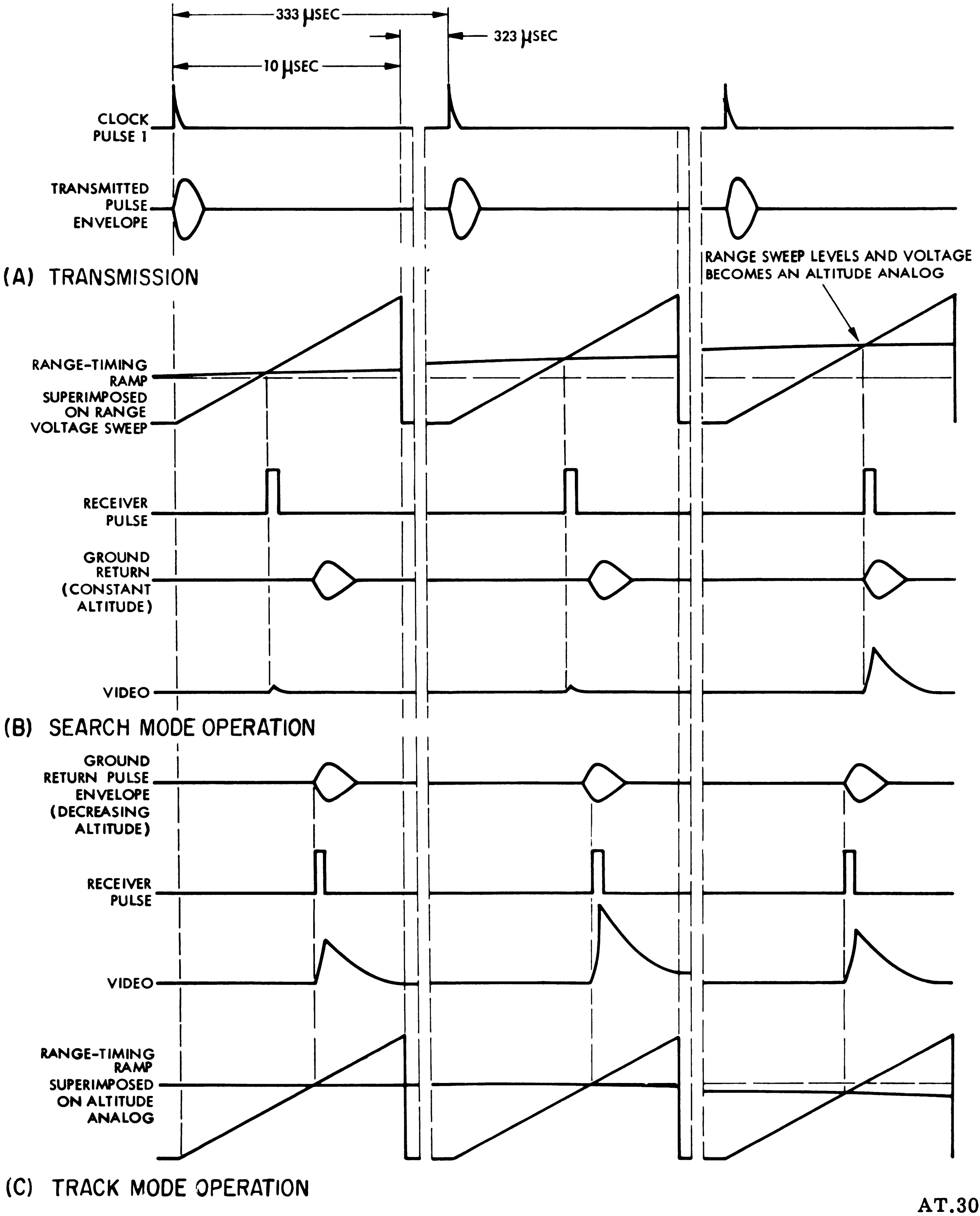
In the tracking mode, the range voltage still tends to rise, but with a much shallower slope than in the search mode. The tracking servoloop utilizes both this slight tendency of the range voltage to rise if uncontrolled and the sensitivity and power buildup characteristics of the receiver cavity as a governing mechanism for locking onto and tracking altitude changes. At the leading edge of the receiver pulse, cavity sensitivity rises sharply to a maximum value and then falls off exponentially to a zero value near the trailing edge of the grid pulse.

The center set of curves in figure 17-3(D) shows the operation of this governing mechanism at a constant altitude. Here the leading edge of the grid pulse is timed to coincide with a nominal power level on the leading edge of the ground return pulse. The point of maximum cavity sensitivity coincides with this nominal RF power level. The buildup of cavity output power, because of the exponential curve of the sensitivity characteristic, is linear. Averaged over succeeding cycles of operation, the buildup is just sufficient to keep the range voltage at a constant level, maintaining a constant period of ramp and range voltage coincidence and a consequent fixed grid-pulse spacing. The results are a steady d-c voltage analog to the height indicator and a constant altitude indication.

The lower set of waveforms in figure 17-3 (C) shows how the system tracks a ground return pulse train whose period shortens successively with decreasing altitude. The second receiver pulse, whose spacing from the first pulse is governed by the previous coincidence of ramp and range voltage, occurs slightly delayed with respect to the ground return pulse. Receiver cavity buildup of video output power increases and drives down the range voltage and altitude analog. This causes range and ramp voltage coincidence to occur earlier and the receiver pulse to follow the leading edge of the ground return pulse.

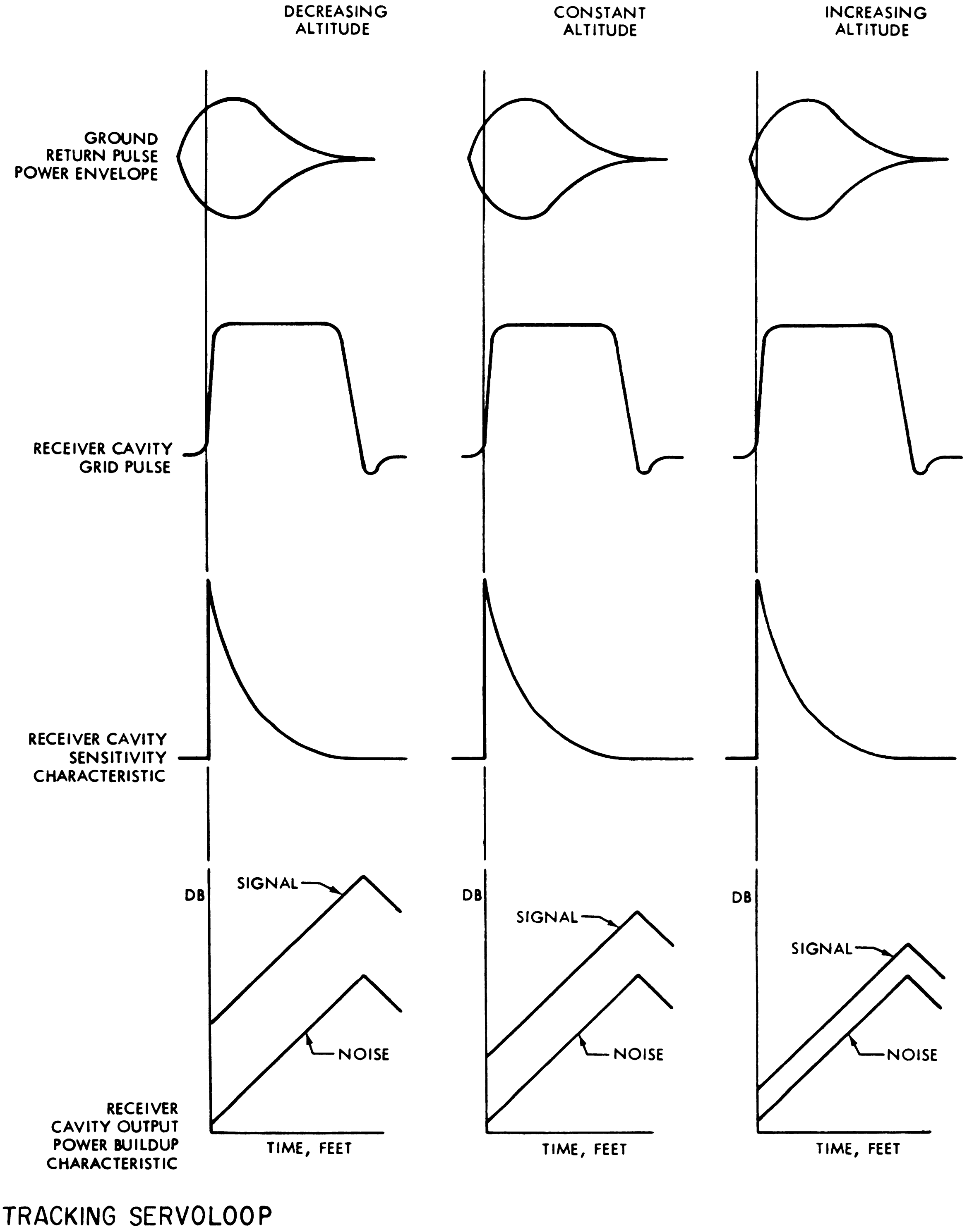
The left set of curves in figure 17-3(D) shows the operation of the tracking servoloop with a decreasing altitude (or with any tendency of the grid-pulse spacing to drive toward a longer period than that required for tracking). The ground return pulse arrives slightly earlier than for a constant altitude, and the leading edge of the grid pulse coincides with a higher power level on the leading edge of the ground return pulse. The consequent higher peak buildup of cavity output power, averaged over a number of operational cycles, drives the range voltage and altitude analog down.

The right set of curves in figure 17-3(D) shows the operation with increasing altitude (or with any tendency of the grid-pulse spacing to drift toward a shorter period than that required for tracking.) The ground return pulse arrives slightly later than for a constant altitude, and the leading edge of the grid pulse coincides with a lower power level. The consequent lower peak buildup of cavity output power, averaged over a number of cycles, allows the range voltage and altitude analog to rise. Thus, the time coincidence of the ramp and range voltage, controlled by the amount of peak video power developed from the initial level of RF signal power at the leading edge of the grid pulse, adjusts the spacing of the receiver pulse automatically to track the leading edge of the ground return pulse. The resulting altitude analog, which follows the range voltage, thus tracks a balance of two op-


333 μSEC
323 μSEC
10 μSEC
CLOCK PULSE 1
TRANSMITTED PULSE ENVELOPE
(A) TRANSMISSION
RANGE SWEEP LEVELS AND VOLTAGE BECOMES AN ALTITUDE ANALOG
RANGE-TIMING RAMP SUPERIMPOSED ON RANGE VOLTAGE SWEEP
RECEIVER PULSE
GROUND RETURN (CONSTANT ALTITUDE)
VIDEO
(B) SEARCH MODE OPERATION
GROUND RETURN PULSE ENVELOPE (DECREASING ALTITUDE)
RECEIVER PULSE
VIDEO
RANGE-TIMING RAMP SUPERIMPOSED ON ALTITUDE ANALOG
(C) TRACK MODE OPERATION

AT.305

Figure 17-3.–Basic system timing sequence.


DECREASING ALTITUDE
CONSTANT ALTITUDE
INCREASING ALTITUDE
GROUND RETURN PULSE POWER ENVELOPE
RECEIVER CAVITY GRID PULSE
RECEIVER CAVITY SENSITIVITY CHARACTERISTIC
DB
SIGNAL
NOISE
TIME, FEET
RECEIVER CAVITY OUTPUT POWER BUILDUP CHARACTERISTIC
(D) TRACKING SERVOLOOP

AT.306

Figure 17-3.–Basic system timing sequence–Continued posing forces—the tendency of the range voltage to rise as the output of a shallow sweep generator, and the force of the average video power that drives the outputs of the sweep generator down.

ALTITUDE INDICATION.—The height indicator is a servo-driven device that positions the pointer at an altitude proportional to the d-c voltage analog from the receiver. In addition, the indicator provides two alerting functions. An OFF flag comes into view in the center of the indicator dial whenever the altimeter is not tracking a ground return signal. A low altitude warning system, which can be set to any altitude from 0 to 5,000 feet, causes a red warning light (in some aircraft installations) on the aircraft instrument panel to illuminate when the aircraft descends below the preset altitude.

BENCH TEST AND CALIBRATION

Most of the later electronic altimeters require the use of a specific test set that is designed only for that particular model altimeter. Some altimeters, such as Electronic Altimeter Set AN/APN-120, are a part of a larger navigation system and have the advantage of being checked for operation and calibration while installed in the aircraft by the use of the aircraft system computer.

Other altimeter types can only be checked in the aircraft by the use of a test set commonly known as a "GO-NO GO checker." This test set is normally a fixed delay line. Test sets of this type are discussed under line test equipment in chapter 8 of this manual.

The Integrated Weapons Shop Test Set AN/USM-124 is specifically designed for shop bench test and for calibration of the AN/APN-120 altimeter. By using the Line Test Set AN/USM-125, a programed tape, and the aircraft computer, faulty units can be located very readily during line maintenance.

The AN/APN-141(V) altimeter also has its own bench test set, Altimeter Test Bench Set TS-1979A/APN-141(V). Any time that maintenance is to be performed on either the transmitter-receiver or the RF switching unit, both units must be calibrated as a matched pair with the bench test set.

Earlier altimeters, such as the AN/APN-22 and AN/APN-117, utilize the Radar Test Set AN/APM-66. This test set also provides a means of calibrating, checking the operation, and facilitating the maintenance of both sets. A unit of this test set (Delay Line MX-1381/APM-66) provides a "GO-NO GO" test for line maintenance of either altimeter. The electronic control amplifiers and the transmitter-receiver units must be calibrated on the test bench as a matched set for proper operation in the aircraft.

RADIO RANGES AND RELATED FACILITIES

A radio range is a CW station, whose radiation produces directional courses or "tracks." These courses remain stationary with respect to the surface of the earth, and serve to guide aircraft over long distances.

OMNIDIRECTIONAL RANGE

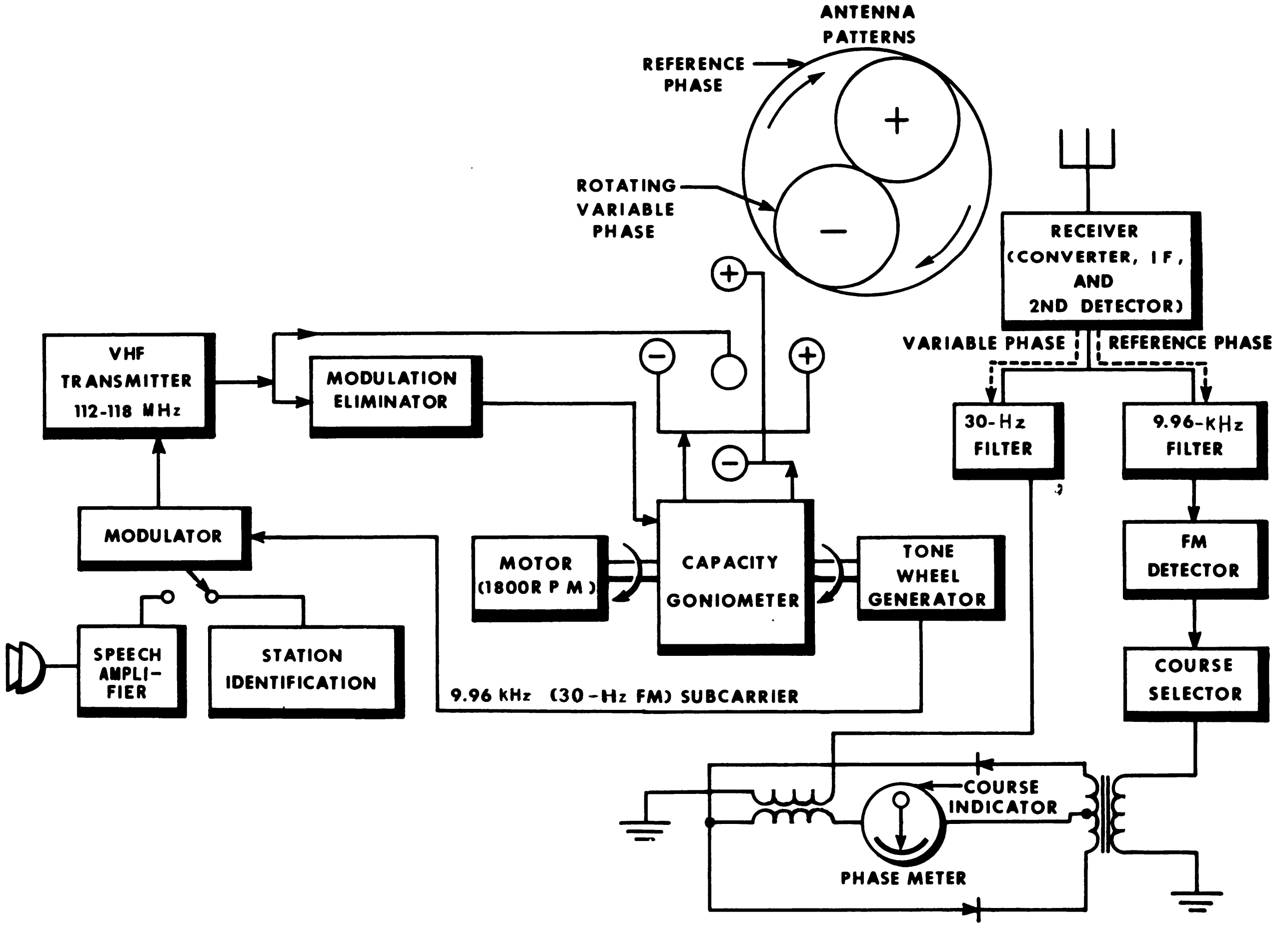
As the name VOR (VHF, omnidirectional range) implies, the omnidirectional or all-directional range station provides the pilot with courses from any point in its service area. It produces an unlimited number of radials, any one of which is a radio path connected to the station. The radials should be considered as lines which originate at the station and radiate outward like the spokes of a wheel. Operation is in the VHF portion of the radio spectrum with the result that interference from atmospheric and precipitation static is negligible. The navigational information is presented in a visual form, is constantly available, and is provided regardless of the position of the aircraft in the service area.

The basic provision of the VOR facility is a means of determining the angular position, or azimuth, of an aircraft with respect to the station. This measurement is made in the airborne receiver which determines the phase difference of two 30 hertz tones derived from two signals radiated from the range station transmitting antenna array. One signal, called the reference phase, is broadcast in a nondirectional radiation pattern. At all points on a circle having the station as its center, corresponding parts of this 30 hertz modulation occur at exactly the same time. Since the phase of this signal is independent of azimuth, it is used as a reference for comparison with another 30 hertz variation derived from a signal called the variable phase.

The variable phase signal is radiated in a figure-of-eight pattern which revolves about the transmitting antenna in a way somewhat similar to a rotating searchlight beam. The pattern consists of a positive and a negative lobe which turn together at 1,800 rpm (30 rps). As a result of the rotation of the pattern, the signal induced in the receiver is amplitude modulated with 30 hertz variations. The receiver develops this tone and compares it with the reference signal. The amount of phase difference between the two depends on the location of the aircraft with respect to the station. A phase measuring circuit in the receiver enables the pilot to determine the magnetic bearing, and also to select and fly a range course to the station on any desired bearing.

As shown in figure 17-4, the VOR transmitter is modulated both by a 9.96 kHz subcarrier and by an additional component either of voice or the station identification code characters. The subcarrier is frequency modulated at 30 Hz and is generated by a notched tone wheel rotating in a magnetic field. The purpose of the subcarrier is to provide a means for separating the 30 hertz tone of the reference phase from the variable tone of the same frequency.

The modulated output of the transmitter is applied both to a modulation eliminator and to the center loop antenna of a five-element array. There it is radiated to form the reference phase signal. The modulation eliminator is a clipper which removes the amplitude modulation from the carrier. The unmodulated output is fed to a



AT.307

Figure 17-4.—Omnirange system fundamentals.

capacity goniometer which serves as a mechanical sideband generator. The goniometer is a motor-driven, double capacitor in which one set of stator plates is displaced 90° from the other set. The rotor plates to which the RF signal is applied are driven at 1,800 rpm (30 rps).

Two outputs are derived, one from each set of stator plates. These two signals contain modulation components (30 Hz) which differ in phase by 90° because of the capacitor plate relationship. One output is fed to one pair of diagonally opposite loop antennas, and the other is fed to the remaining pair of loops in the square array. Each pair of corner antennas produces a figure-of-eight radiation pattern. These two patterns are displaced from each other by 90° both in space and in time phase. The resultant pattern is the sum of the two crossed figure-of-eight patterns and consists of the rotating field described above.

Figure 17-4 shows in simplified form the essential elements of the receiver which enable the pilot to select and fly a range course to the omnidirectional station. In the VOR transmitting system, the reference and the variable signals are in phase along the 0° radial (bearing due north of the station). The phase difference between the signals changes proportionately with the change in bearing to the station. The airborne receiver measures the magnetic bearing of the range station by the following general method:

1. The reference and variable signals are received and separated.
2. The two signals are then applied to a phase bridge containing a zero-center meter (the vertical pointer instrument used with the ILS localizer beam).
3. The reference signal is applied through a phase shifter, or course selector, equipped with a dial calibrated in degrees from 0 to 360.
4. The reference signal is shifted (in phase) by adjustment of the calibrated course selector until the phase bridge is brought to a zero indication. The amount of phase shift required to zero the bridge is proportional to the magnetic bearing of the range station.

To fly a given course to the station, the pilot sets the phase shifter until the calibrated dial reads the desired course. With this setting the reference signal is phased so that a balanced condition of the course indicator needle is shown as long as the aircraft is on the selected radial. To follow the radial to the station (usually described as "flying inbound"), the pilot flies so as to keep the vertical needle of the course indicator in the center position. The terms RADIAL and COURSE do not always mean the same thing. To fly INBOUND on the 045° radial, the pilot must fly a course of 225°. To fly INBOUND on a course of 130°, the pilot must use the 310° radial.

As indicated in figure 17-4, the receiver is an ordinary superheterodyne through the second detector. Following the second detector, filter circuits separate the 9,960 hertz subcarrier and the variable phase 30 hertz signals. The FM subcarrier is then applied to an FM detector which recovers the 30 hertz reference voltage. After passing through the phase shifter (course selector), the reference voltage is combined with the variable signal in the phase meter circuit.

The phase meter is a bridge which is balanced (indicated by a center position of the course indicator) when the two 30 hertz variations applied to it differ in phase by 90°. With this relation, the vector sum of the voltages in the upper half of the circuit is equal to the vector sum of those in the lower half. The two sums are converted into d.c. by rectifiers and applied to the zero-center instrument with opposite polarity.

The phase shifter contains two transformer windings mounted at right angles, and these two are fed with two components of the reference signal. A third winding rotates inside the other two coils, and a voltage is induced in it with a phase angle which depends on the rotor position with respect to the two primaries. The rotor coil is attached to a counter type dial which is calibrated in degrees to indicate the magnetic bearing to the omnirange station. A manually adjustable set knob is used to position the rotor for the desired magnetic course.

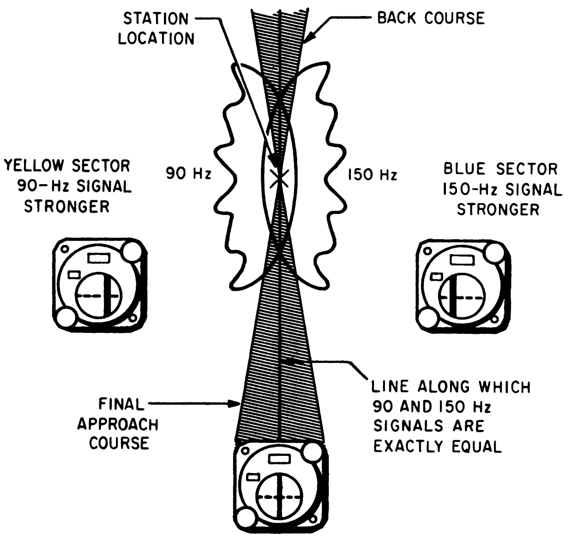
The vertical pointer of the course indicator remains in the center as long as the aircraft is on the selected course line, whether inbound or outbound. (This results from the fact that there are two positions of the phase shifter which will balance the bridge circuit.) Since the course line consists of two radials which are reciprocals of each other, an indicator is needed so that the pilot will know which radial (that is, which side of the station) he is on. The TO-FROM indicator tells the pilot whether the selected course line, once he is on it, will take him to the station or from the station.

For example, suppose the aircraft is on the 90° radial. To fly to the station, the pilot takes a heading of 270° and dials 270° on the course selector. The TO-FROM indicator reads TO while the aircraft is approaching the station from the east. After passing over the station, continuing westbound, the TO-FROM indicator reads FROM.

INSTRUMENT LANDING SYSTEM

The instrument landing system, (ILS), one of the facilities of the federal airways, operates in the VHF portion of the spectrum. The entire system consists of a runway localizer, a glidepath signal, and marker beacons for position location.

The localizer equipment produces a radio course alined with the center of an airport runway. The on-course signal results from equal reception of two signals-one containing 90 hertz modulation, and the other containing 150 hertz modulation. On one side of the runway centerline, the radio receiver develops an output in which the 150 hertz tone predominates. This area is called the blue sector. On the other side of the centerline, the 90 hertz output is greater. This area is called the yellow sector.


STATION LOCATION
BACK COURSE
YELLOW SECTOR 90-Hz SIGNAL STRONGER
90 Hz
150 Hz
BLUE SECTOR 150-Hz SIGNAL STRONGER
FINAL APPROACH COURSE
LINE ALONG WHICH 90 AND 150 Hz SIGNALS ARE EXACTLY EQUAL

AT.308

Figure 17-5.—Tone localizer pattern and instrument indications.

In the aircraft receiver, the output circuit contains a balanced rectifier connected to a zero-center microammeter which remains centered as long as equal amounts of the two tones are present. Deviation of the aircraft to either side of the final approach course results in deviation of the indicator as shown in figure 17-5.

The localizer transmitter operates at about 110 MHz. The transmissions are made from an antenna array containing eight loops situated about 1,500 feet from the end of the runway. Three kinds of transmissions are made. Six of the loops radiate sideband energy only. Sidebands containing 90 hertz modulation and those bands containing 150 hertz modulation are separated by a sharp null directed along the centerline of the runway. Two of the loops radiate the carrier wave containing equal amounts of 90 hertz and 150 hertz tones, and this signal is sent along the null separating the sectors. Signals are received in any location; but as indicated in the figure, only along the runway centerline are the 90 hertz and 150 hertz tones received in exactly equal amounts.

The glidepath is a radio beam which gives vertical guidance to the pilot, assisting him in making the correct angle of descent to the runway. Glidepath signals are radiated from two antennas which are driven by a crystal-controlled transmitter operating at about 330 MHz. The power output is about 25 watts.

One antenna radiates a beam which is very broad in the vertical plane. This beam contains signals modulated by a 90 hertz tone. The other antenna emits signals modulated at 150 hertz in many lobes which are very narrow in the vertical plane. The undesired lobes are too high (fig. 17-6) to be encountered in a normal approach. The glidepath is an area of intersection between the broad 90 hertz lobe and the lowest of the 150 hertz lobes. In this area, which is a conical beam, the receiver develops equal amounts of 90 hertz and 150 hertz signals in the output. The beam is inclined about 2.5° with the horizontal.

The glidepath receiver is a crystal-controlled superheterodyne which is powered entirely from a 28-volt, d-c source and requires no high voltage power. The receiver audio output containing the 90 hertz and 150 hertz tones is filtered, and the two signals are rectified separately. The resulting direct current is applied to a zero-center microammeter which indicates by means of a horizontal pointer. (The localizer and glidepath indicators are actually mounted on the same instrument. However, in many military installations the glidepath equipment is not employed.) The pilot flies the glidepath by keeping the horizontal pointer in the center of the dial.

Figure 17-6 shows how the glidepath would appear. The cross section is shown from the runway to a distance of 10 miles. At that range the glidepath appears to be 920 feet thick (vertically) and 4,600 feet wide. By keeping both pointers centered, the pilot may fly to the runway without seeing the ground. However, once over the runway, the pilot must be able to see the runway in order to land.

Marker beacons and compass locators are used in connection with the instrument landing system. The markers are signals which indicate the position of the aircraft along the approach to the runway. Two markers are used in each installation. The location of each is identified both by tone modulation and by a signal lamp. The outer marker is located about 4.5 miles from the end of the runway. The signal is modulated by a 400 hertz tone and is keyed in long dashes (two dashes per second). The inner marker, located at a distance of 3,500 feet, is modulated at 1300 hertz (a higher pitched tone) and is keyed with alternate dots and dashes.

Compass locators are low-power nondirectional beacons which provide signals for automatic direction-finding equipment. They operate between 200 kHz and 400 kHz and are located near the marker beacon transmitters. The locator near the outer marker is coded with the first two letters of the localizer transmitter identification letters, and the locator near the inner marker employs the last two letters of the call signal.

DISTANCE MEASURING EQUIPMENT

Eventually, each omnirange station will be equipped with distance measuring equipment (DME). By means of this facility, the pilot is provided with constant visual indication of his distance from the range station; and the combined VOR and DME data include all the information required for point-to-point navigation. These data consist of exact knowledge of the

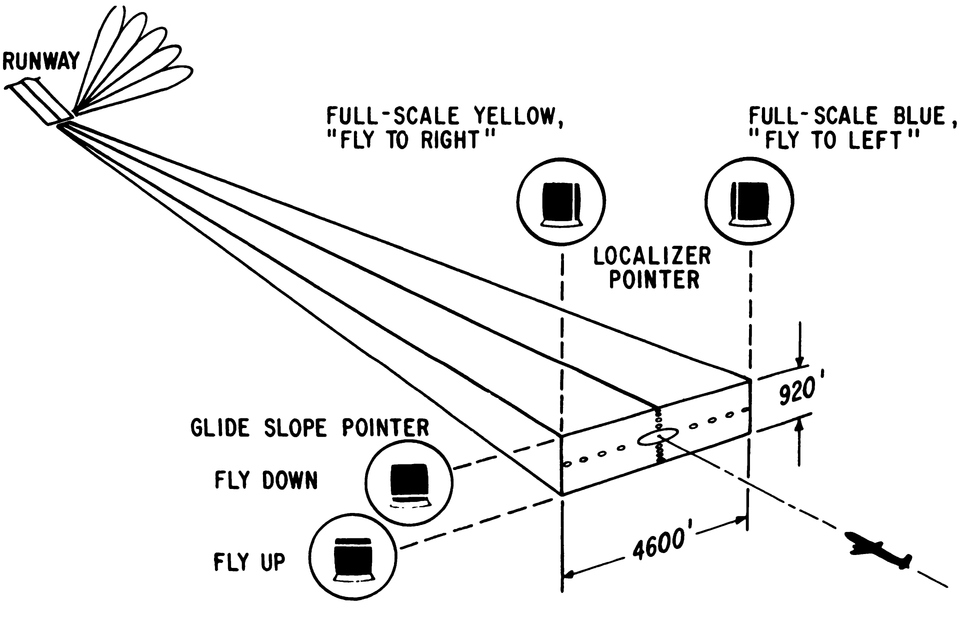


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Figure 17-6.—Cross section of ILS course.

distance of the aircraft from one or more range stations together with the direction of each.

The operation of DME units is similar to that of IFF. The airborne unit, called the interrogator, transmits a train of short pulses which are received by the ground unit, called a transponder. After reception of the challenging pulses, the ground station uses suitable circuits to shape them into trigger impulses which modulate a pulse transmitter to send a reply to the aircraft. Upon reception of the signal by the interrogator, the elapsed time between the challenge and the reply is measured. This interval is a measure of the distance separating the aircraft and the transponder station.

The challenge sent by the aircraft consists of spaced pulses in the 960-990 MHz band. The ground station equipment is set to accept only those signals which have the correct spacing and which are on the correct frequency. The frequency and the pulse spacing characteristics define a challenge channel. The reply consists of a train of RF pulses in the 1185-1215 MHz band. The combination of the challenge and reply channels is called an operating channel.

Up to 50 aircraft can use the same ground station to obtain DME information without interference.

A typical airborne unit, shown in block diagram form in figure 17-7, consists essentially of timing circuits, search and tracking circuits, and the indicator meter.

The timing circuits measure the time interval between the transmission of a challenging pulse from the transmitter and the reception of the corresponding reply pulses. As in radar operation, this time value is a measure of the distance separating the aircraft and the station.

The search circuits operate by causing the equipment to seek out a reply after each challenge. Briefly, the search function is as follows: The receiver is triggered on by gating circuits and operates for a very brief period of time after each challenge. The gate pulse which activates the receiver is separated from the

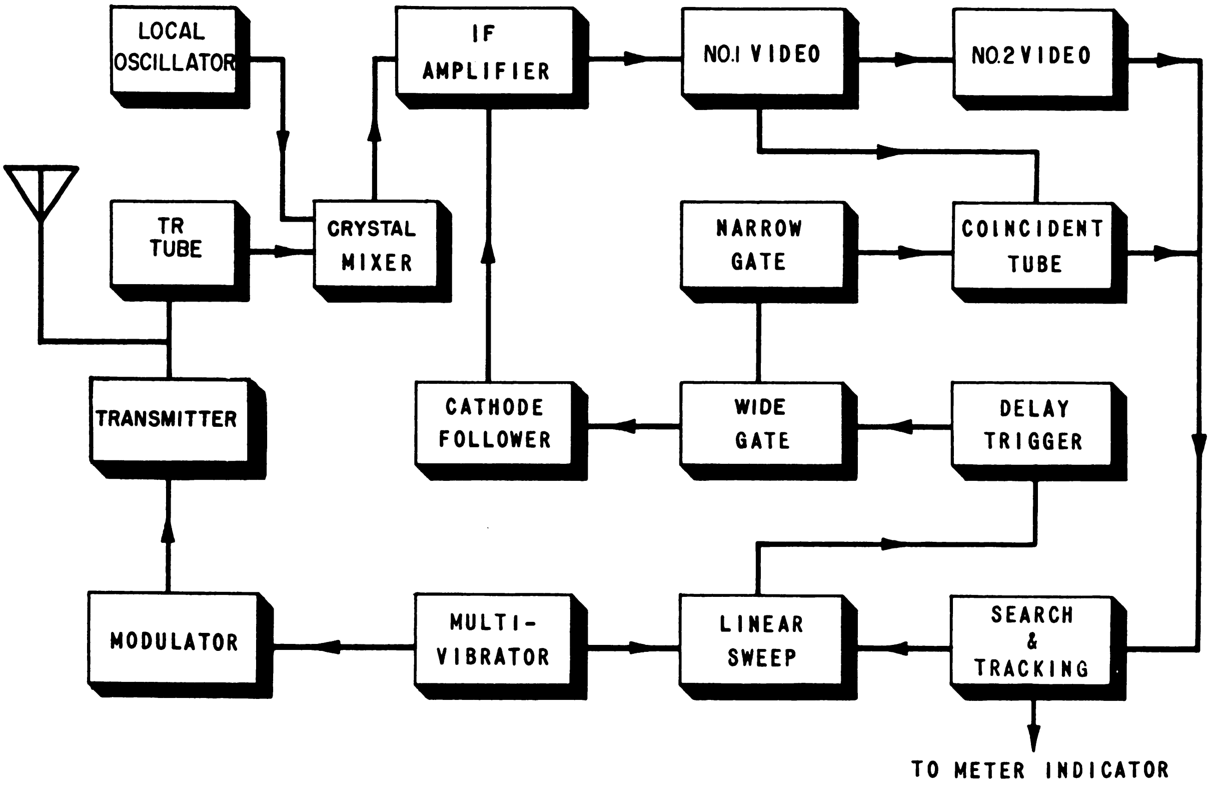

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Figure 17-7.—Block diagram of a typical DME system.

challenge by an interval of time delay, T. Interval T is made to vary between 0 and 1,200 microseconds, corresponding to a range of distances from 0 to approximately 112 miles. The receiver goes into operation after each challenge, but is delayed by a different interval of time after each emitted signal. The receiver can accept beacon replies only when the delay time, T, is equal to the time required for a challenge signal to reach the station and the reply to return. When the time delay is such that the station reply is received, the search circuits are disconnected and the tracking operation begins. During tracking, the receiver holds the signal which it has found. When this occurs, the distance of the station is indicated on the dial of the indicator. This is accomplished by measuring the delay time, T. The value of T is controlled by a voltage to which it is directly proportional. When the search circuits have discovered a reply, the control voltage is applied to the voltmeter which is calibrated in miles.

The tracking circuits of the equipment adjust the time of operation of the receiver so that the receiver station reply is accepted even though the distance between the aircraft and the ground station is constantly changing. In tracking operation, the receiver is controlled by the action of two gating impulses--the wide gate (20 microseconds) and the narrow gate (10 microseconds). A signal received in the wide gate increases the delay time, and one received during the narrow gate decreases it. Thus the two control gates effectively bracket the reply signal and keep the receiver operating at the time when the reply pulses arrive. As a result, the distance meter continually indicates the number of miles between the aircraft and the station.

The automatic search circuits can be started again when the pilot wishes to track on another station. If the new station is more distant than the first, a release switch is pressed which causes the delay to increase. The search circuits then begin operating to seek out the delay time corresponding to the station. If the alternative beacon is nearer than the first, a zero switch is pressed which causes the delay time to start again from zero before resuming search operation.

A pilot lamp, found in some installations near the DME meter, indicates the presence or absence of a signal, and is illuminated if no signals are present. The station transmissions are gap-coded; that is, the replies are arranged so that intervening spaces form the Morse code letters assigned to identify the station. When the signals are being received, the pilot lamp flashes on and off, giving the station code identifier. When the aircraft is at a distance beyond the operating range of the station, the light burns continuously to warn the pilot that the meter reading is no longer the true distance but is the distance at which the signal was last received.

TACAN SYSTEM

TACAN, standing for TACtical Air Navigation, is an air navigational system operating at UHF frequencies to provide aircraft with continuous accurate range and bearing information. The system consists of an airborne UHF transmitter-receiver (AN/ARN-21) and a surface station (AN/URN-3). Bearing information is accurate to within 0.25°. The maximum slant range is 195 nautical miles with an error of less than 1,000 yards. The error at close range is less than 200 yards. The system has 126 two-way operating channels in the range of 962 to 1213 MHz. Each channel uses two separate frequencies spaced 63 MHz apart. Adjacent channels are separated by 1 MHz. Each of the 126 channels is capable of providing full service without interference to over 100 aircraft. The method used by the system to transmit bearing information is similar to that of the VOR, and the range information is similar to that of the DME. A simplified block diagram of a complete system is shown in figure 17-8.

Both the AN/ARN-21 and the AN/URN-3 contain a receiver and a pulsed transmitter. The surface station continually transmits signals consisting of randomly spaced pulse pairs, pulse-pair distance replies, and evenly spaced and coded groups of paired pulses. Due to the antenna configuration and rotation, all of these signals arriving at a given location are amplitude modulated at both 15 and 135 Hz. The surface station transmits approximately 3,600 pulse pairs per second. The main azimuth reference burst is transmitted each time the antenna passes a given azimuth (usually magnetic east) and consist of 12 pulse pairs with 30 microseconds between pairs. The antenna rotates at 15 rps (12 x 15 equals 180 pulse pairs per sec-

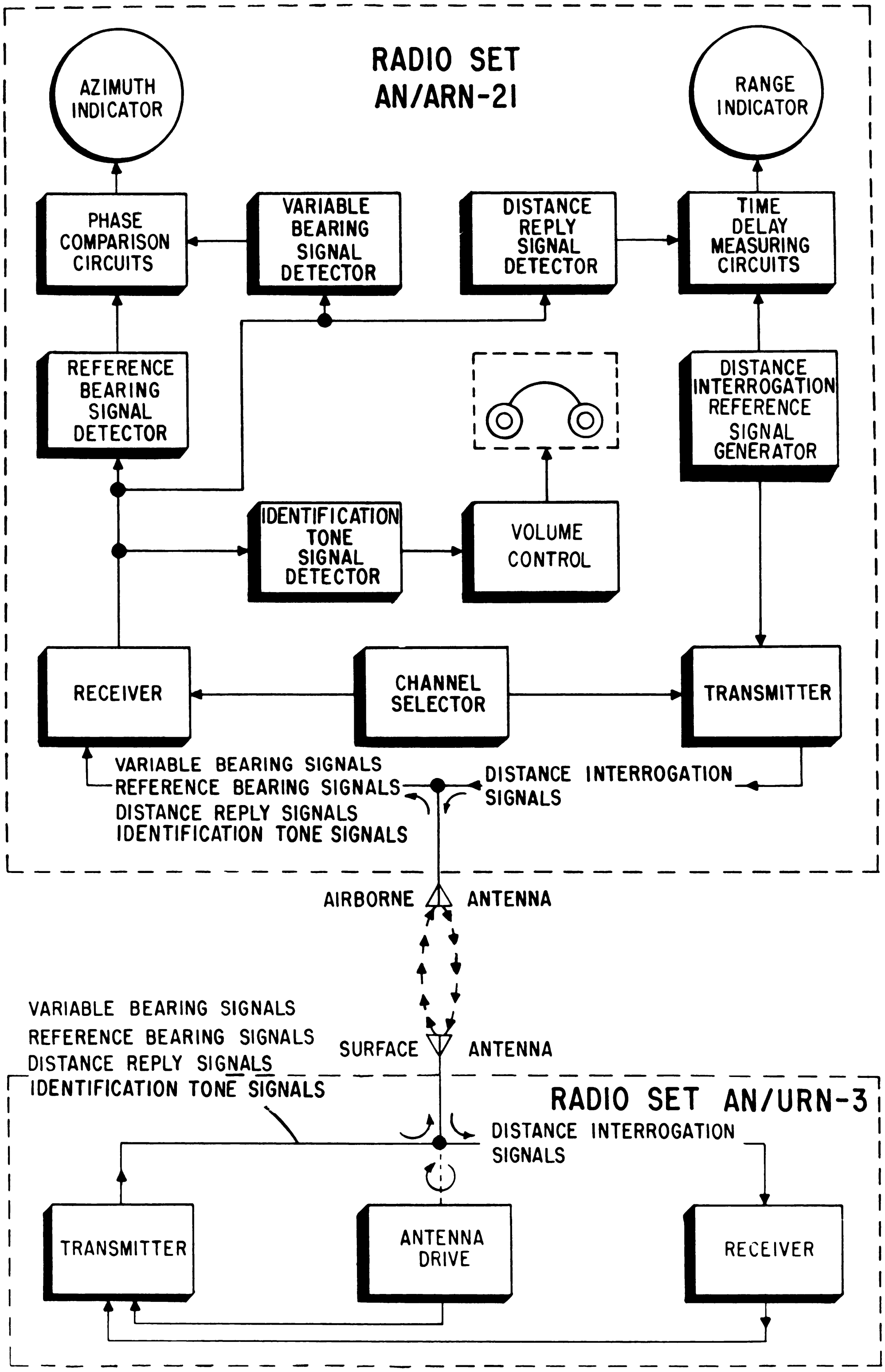
RADIO SET AN/ARN-21
AZIMUTH INDICATOR
RANGE INDICATOR
PHASE COMPARISON CIRCUITS
VARIABLE BEARING SIGNAL DETECTOR
DISTANCE REPLY SIGNAL DETECTOR
TIME DELAY MEASURING CIRCUITS
REFERENCE BEARING SIGNAL DETECTOR
DISTANCE INTERROGATION REFERENCE SIGNAL GENERATOR
IDENTIFICATION TONE SIGNAL DETECTOR
VOLUME CONTROL
RECEIVER
CHANNEL SELECTOR
TRANSMITTER
VARIABLE BEARING SIGNALS
REFERENCE BEARING SIGNALS
DISTANCE REPLY SIGNALS
IDENTIFICATION TONE SIGNALS
DISTANCE INTERROGATION SIGNALS
AIRBORNE ANTENNA
VARIABLE BEARING SIGNALS
REFERENCE BEARING SIGNALS
DISTANCE REPLY SIGNALS
IDENTIFICATION TONE SIGNALS
SURFACE ANTENNA
RADIO SET AN/URN-3
DISTANCE INTERROGATION SIGNALS
TRANSMITTER
ANTENNA DRIVE
RECEIVER

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Figure 17-8.—Simplified block diagram of the TACAN system.

ond). The auxiliary reference bursts are transmitted eight times during one revolution of the antenna and consist of 6 pulse pairs with 24 microseconds between pairs (8 x 15 x 6 equals 720 pulse pairs per second). This gives a total of 900 pulse pairs per second used for azimuth reference signals. The remaining 2,700 pulse pairs per second are transmitted at random. Some of these random pulse pairs are controlled by distance interrogation signals from aircraft to give distance replies. Also, at intervals (usually every 37.5 seconds), the random pulse pairs are replaced by pulse pairs with fixed spacing arranged to form Morse code.

Whenever the surface station receives a distance interrogation pulse-pair from any aircraft, it transmits a pulse-pair reply (using one of the 2,700 random pulse pairs) exactly 50 microseconds after receiving the interrogating pulse pair.

TACAN ANTENNA

The AN/URN-3 antenna consists of a central stationary driven element with a rotating array of one main parasitic reflector element and nine auxiliary parasitic reflector elements to give an antenna pattern that is a combination of a cardioid with nine lobes superimposed on it. (See fig. 17-9.) Every time the main lobe of the antenna passes magnetic east, the AN/URN-3 transmits the main reference burst of 12 pulse pairs (30 microseconds between pairs). Every time one of the other eight auxiliary lobes passes magnetic east, the AN/URN-3 transmits an auxiliary azimuth reference burst of 6 pulse pairs (24 microseconds between pairs). Since the pattern is rotating at 15 rps, an aircraft in the position shown would receive a signal containing pulse pairs amplitude modulated at both 15 Hz and 135 Hz. (See fig. 17-10.) One is called the 15 Hz variable bearing signal, and the other is called the 135 Hz variable bearing signal.

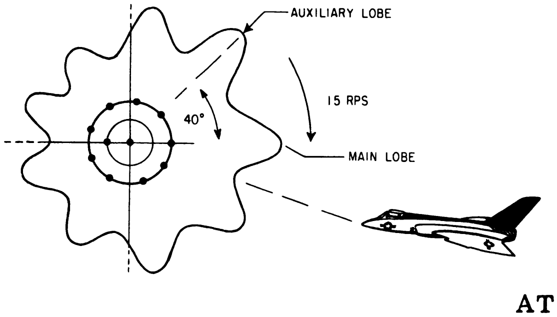

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Figure 17-9.—Rotating antenna pattern of AN/URN-3.

AIR-TO-AIR-TACAN

The original TACAN system was limited to an air-surface application—no provisions were made for air-to-air ranging. However, the newer concept of TACAN includes this feature and uses the AN/ARN-21D or the AN/ARN-52(V) equipment.

In the AN/ARN-21D, the air-to-air link functions primarily because of a modification permitting "image frequency" reception. Ranging is made possible by adding a transponding function to the airborne equipment. Both ends of the link display distance information simultaneously; therefore, the technique is called "bilateral ranging." The TACAN ground station is not involved in the air-to-air link.

The airborne sets receive on frequencies displaced 63 MHz from their transmitting frequencies. Considering the ground station system as normal TACAN, the air-to-air system uses the "image" frequency. This idea is illustrated in figure 17-11.

In both systems, the transmit and receive frequencies are separated by 63 MHz. However, in the normal system, reception is below transmit frequency for channels 1-63 and above for channels 64-126. For the air-to-air (A/A) system, these situations are reversed. Thus, any AN/ARN-21D set for normal operation will not respond to A/A transmissions, regardless of the channel selected. (See fig. 17-12.)

Careful study of figure 17-12 (A) illustrates the following details of TACAN operation:

1. Aircraft A and the ground station set to the same channel, aircraft set on normal mode, operation is normal. Aircraft B and C are not involved.

2. Aircraft B and C are set to channels separated by 63 MHz both aircraft on air-to-air mode, bilateral ranging is performed. Aircraft A and the ground station are not involved.

3. Aircraft A and C are set to the same channel, but on different modes. They do not respond to interrogations by the other aircraft.

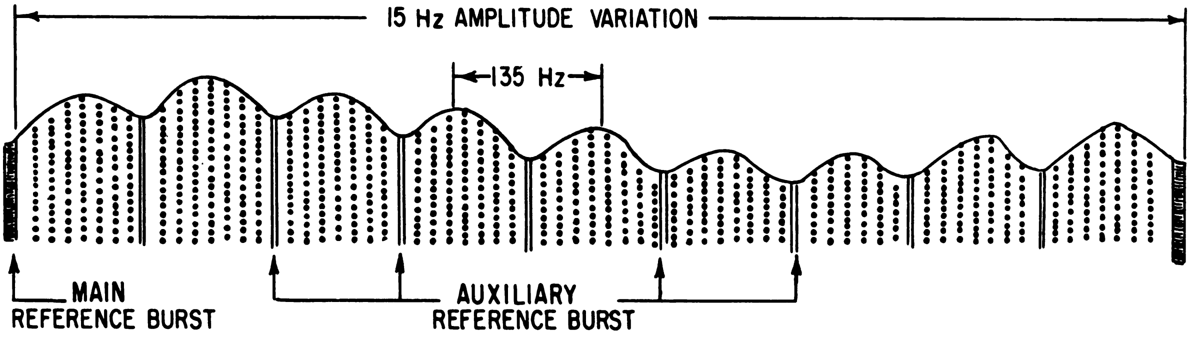

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Figure 17-10.–Signal received by an aircraft at 150°.

Figure 17-12 (B) illustrates the simultaneous ranging of aircraft A and C on aircraft B, but not on each other. Aircraft B will indicate the range to one of the aircraft (which one is mere chance).

In order to prevent aircraft from replying to replies, the interrogation consists of pulse pairs, while replies consist of single pulses. Replies are made only to pulse pairs.

AN/ARN-21 (Series) TACAN Receivers

Radio Set AN/ARN-21B is the general airborne TACAN unit used for air-to-surface operation as described previously. When modified to incorporate the air-to-air capability, the equipment is designated AN/ARN-21D and functions in either mode as selected from the control unit. In principle, operation is similar

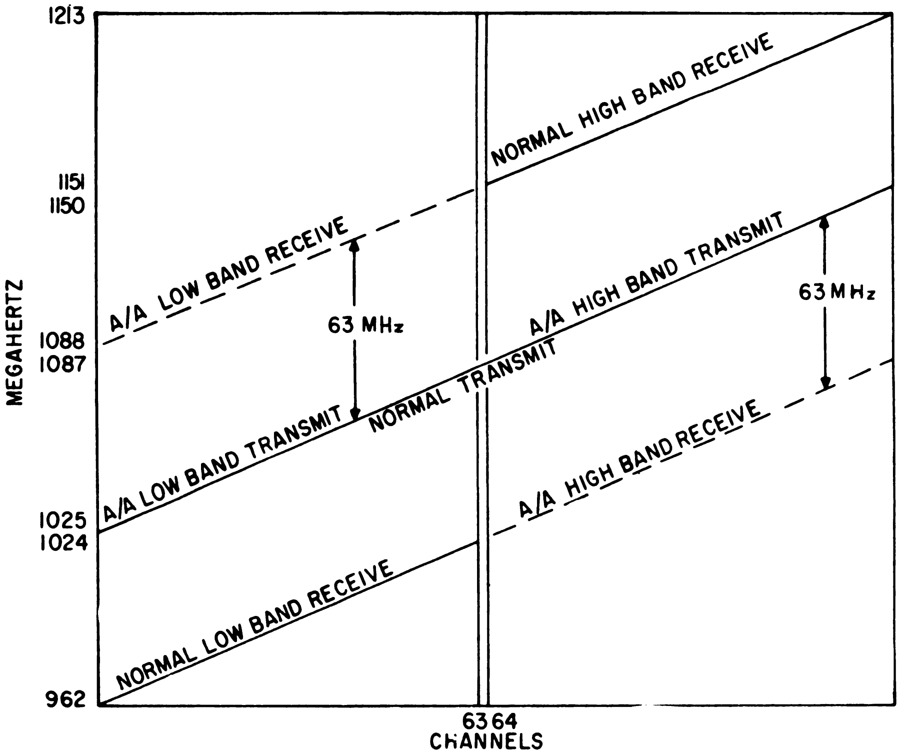

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Figure 17-11.–TACAN frequency spectrum.

to the AN/ARN-52(V) discussed in the following section. The AN/ARN-52(V) is a newer and somewhat improved airborne TACAN unit.

The AN/ARN-21 (Series) uses a 42 MHz oscillator and 42 crystals to produce the frequencies needed for the 126 channels.

The AN/ARN-52(V)

The AN/ARN-52(V) contains additional features and improvements, even though it is slightly smaller and approximately 20 pounds lighter than the AN/ARN-21. In addition to the air-to-surface and air-to-air features, the AN/ARN-52(V) contains built-in range and bearing mechanical modules. Minimum power output has been increased to 1.5 kw, and the range readout has been increased to 300 miles. It also uses 126 crystals—one for each channel, instead of the 42 MHz oscillator and 42 crystals used in the AN/ARN-21B. In air-to-air mode, it responds to a maximum of five interrogating aircraft.

The AN/ARN-52(V) can be adapted to supply and process distance and bearing information for use in various indicators, automatic pilots, and computers. The indicators used in conjunction with this equipment include a bearing-distance-heading indicator (BDHI) such as the ID-663/ARN, a course indicator such as the ID-387, a radio bearing indicator such as the ID

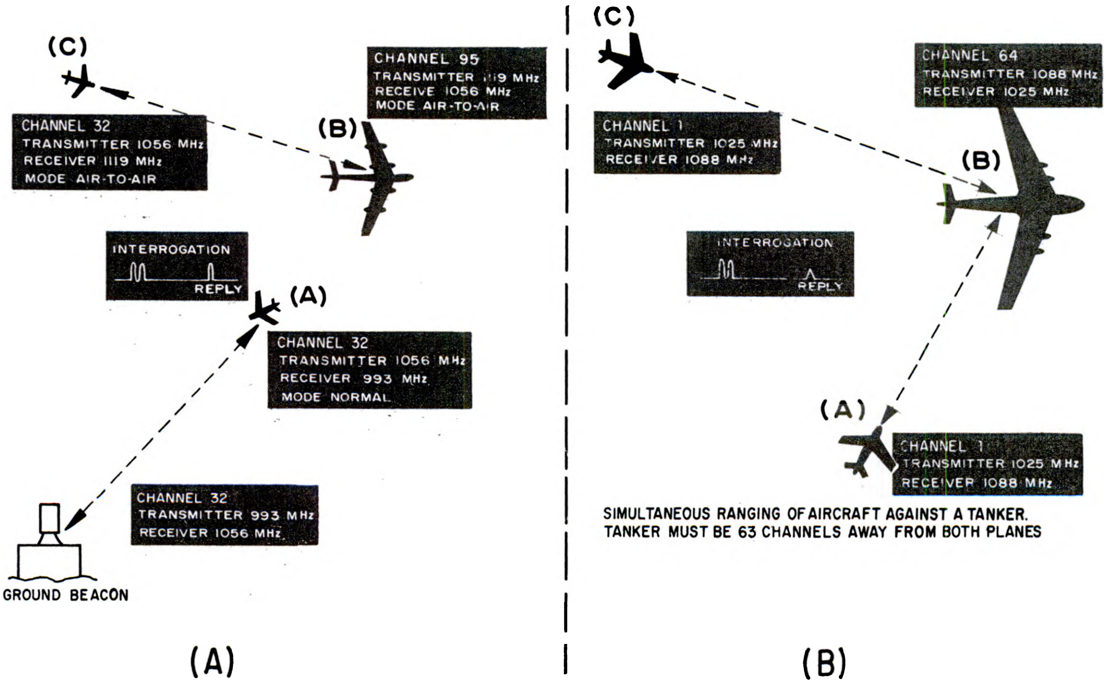

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Figure 17-12.–TACAN system operation.

250, and/or a distance indicator such as the ID-388.

The AN/ARN-52(V) operates in any of three modes. It can receive bearing and station identity information; receive range, bearing, and station identity information, or receive and transmit bilateral air-to-air ranging information.

As installed in an aircraft, the AN/ARN-52(V) uses two antennas mounted in such a manner that any "blind" spot of one antenna is covered by the other. An automatic antenna selector circuit connects the RF circuits to that antenna which provides a usable TACAN signal. In the absence of a usable signal, this circuit switches the equipment back and forth between the two antennas. When a suitable signal is received at one antenna, the equipment is locked to that antenna. Loss of a usable signal initiates a memory period to prevent loss of lock resulting from short-duration transient conditions.

The basic frequency of the selected crystal (42.7 to 47.9 MHz) goes through several stages of multiplication and amplification to produce two outputs at the transmission frequency. One signal is amplified, pulse modulated, and radiated from the antenna. The other signal is used in the crystal mixer as a local oscillator signal to produce the 63 MHz IF signal.

For further details concerning TACAN equipments, refer to the applicable technical manuals.

BENCH TEST AND ALINEMENT

The majority of aircraft TACAN equipment is tested and alined with the use of Radio Test Set AN/ARM-22A. This test set provides air-to-air (A/A) testing capabilities and simulates navigational signals that are normally provided by the Radio Set AN/URN-3 (or other TACAN station radio transmitter), a part of the TACAN system.

The AN/ARM-22A can simulate fixed or variable ranges from 0 to 198 miles, all bearings from 0° to 360°, and tone for operation of the identity circuits of the aircraft TACAN equipment. In addition, the test set can transmit these simulated signals to equipment being tested on any one of 126 preselected channels.

The radio test set may be mounted on a mobile dolly to facilitate flight line testing of airborne components.

When the radio test set is used in conjunction with Test Set Indicator AN/ARM-31, the capabilities of the equipment are increased. The simulated information sent to and then processed by the equipment being tested is displayed on the test set indicator in the AN/ARM-31. This enables the operator to test individual components of the aircraft equipment.

LORAN

The word LORAN is formed from the words LOng RAnge Navigation. It is a navigational system developed primarily to provide a means for making geographical fixes by the use of long range radio signals. The system is a valuable aid to navigation, since loran fixes can be made quickly and accurately both by night and day. It is reliable for both air and surface navigation under most weather conditions. Loran signals can often be received even during storms, except those involving severe electrical disturbances. The principal value of loran lies in its capability of continued operation during conditions which make celestial navigation difficult or impossible. Such conditions include any situation in which the stars are not visible.

PRINCIPLES OF LORAN

In principle, loran differs from radar in that the airborne unit simply receives radio pulses broadcast from ground stations, and no reception of echo signals is involved. The basic loran measurement is that of time difference of arriving signals with no regard to the direction from which they arrive; hence, the complicated directional antennas used in radar equipment are not necessary. Despite these differences, however, loran is closely related to radar since it uses pulse type equipment, and it employs radar techniques of time measurement. Also, visual displays of the signals received are made on cathode-ray tubes used as indicators.

The basic principle of the system is illustrated in figure 17-13. Two stations are necessary to establish a loran line of position. The master station (A) emits a continuous series of uniformly spaced pulses at a stable pulse recurrence rate. The slave station (B) sends out a similar series of pulses which are synchronized with the master pulses. The master and slave stations are usually 200 to 400 miles apart. The line joining the two stations is called the baseline, and the perpendicular at its center is called the centerline. The baseline extension is a straight line drawn beyond either station as a continuation of the baseline.

Assume that the two stations are sending out pulses simultaneously; then at any point along the centerline, the two signals arrive at the

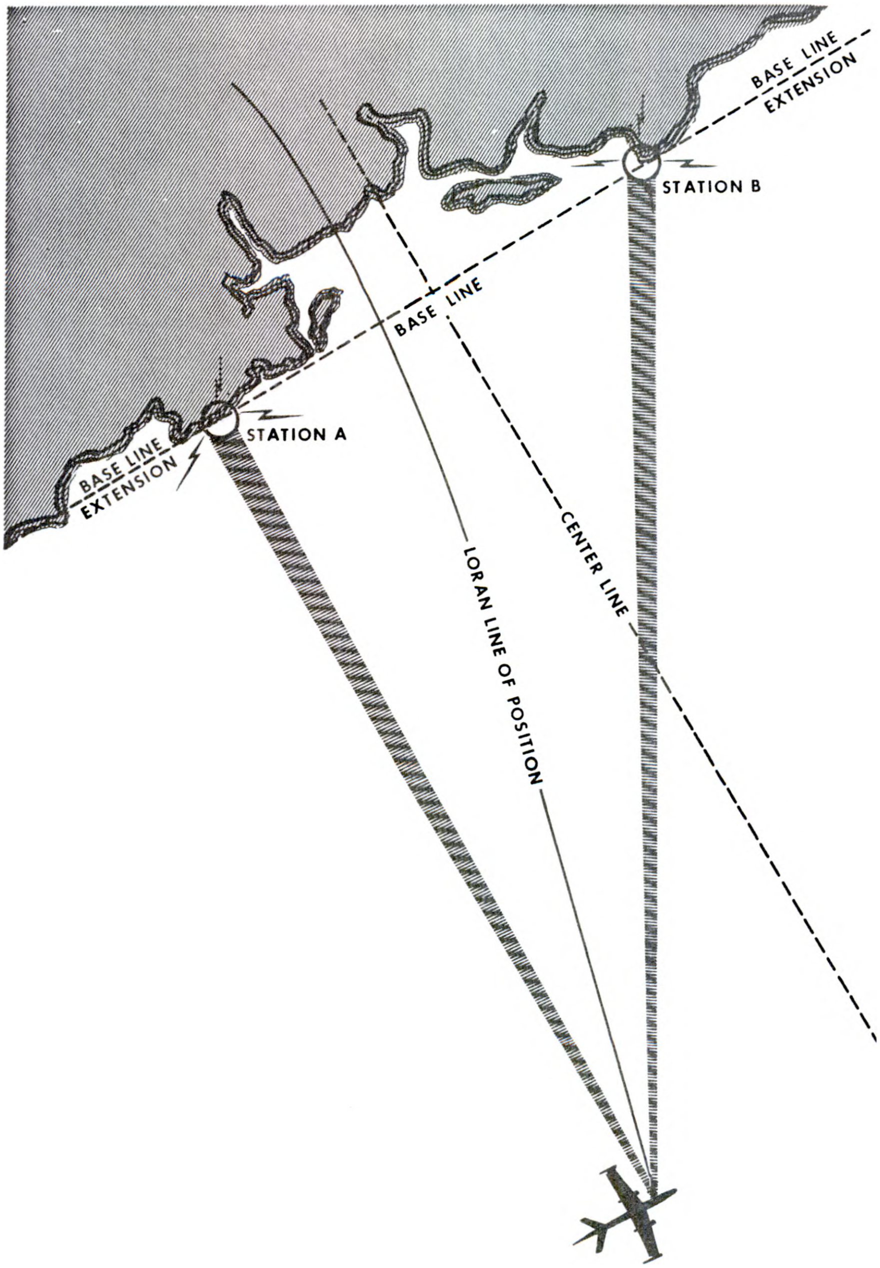

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Figure 17-13.–The principle of loran.

same instant (since all points of the line are equidistant from the two transmitters). If an observer is located nearer station A than station B, the A pulse arrives at his position first, followed (after a measurable time interval) by the corresponding B pulse. By moving to different positions located in the same vicinity, the observer could record the time interval (difference in arrival time of the A and B pulses) corresponding to each position. If several positions having the same time interval were joined by a smooth curve, the curve thus traced would be a line of position for station pair A and B.

The difference in the time of arrival of the pulses corresponds to the difference in distance from the stations, and can be accurately calculated and plotted on a chart. Selected line of position curves may be drawn by connecting points of equal computed time or distance values. Each curve so constructed has the shape of a hyperbola, which is the mathematical name for a curve consisting of points whose difference in distance from two fixed points (in this case, A and B) remains constant. Thus, loran is called a hyperbolic system of navigation.

A large number of lines of position are drawn for each pair of transmitters as shown in figure 17-14. Each line is labeled with a number indicating the time interval in microseconds between the arrival of the corresponding loran pulses.

In (A) of figure 17-14, zero time difference exists along the centerline, while maximum time difference exists along the baseline extensions. Lines with equal time difference may be noted on each side of the centerline, since there is no way to determine which pulse is received from which station. In actual practice, however, the signals are not emitted simultaneously. The slave station pulse is delayed so that, at any point, the master station pulse is received before the corresponding slave pulse. As a result, each curve of the family has a discrete time interval value as indicated in (B).

The delay of the slave pulse includes several increments. The master station transmits a pulse to initiate the sequence of events. An interval of time elapses during which the signal reaches the slave station. The slave station receives the impulses and waits an initial period of time (equal to one-half the pulse recurrence interval) plus an additional period of time (called the coding delay). It then emits a pulse. The sum of the travel time, half the recurrence interval, and the coding delay is called the absolute delay. As a result of the delay, the master pulse always precedes the slave signal at any point of reception. The difference in arrival time is maximum along the baseline

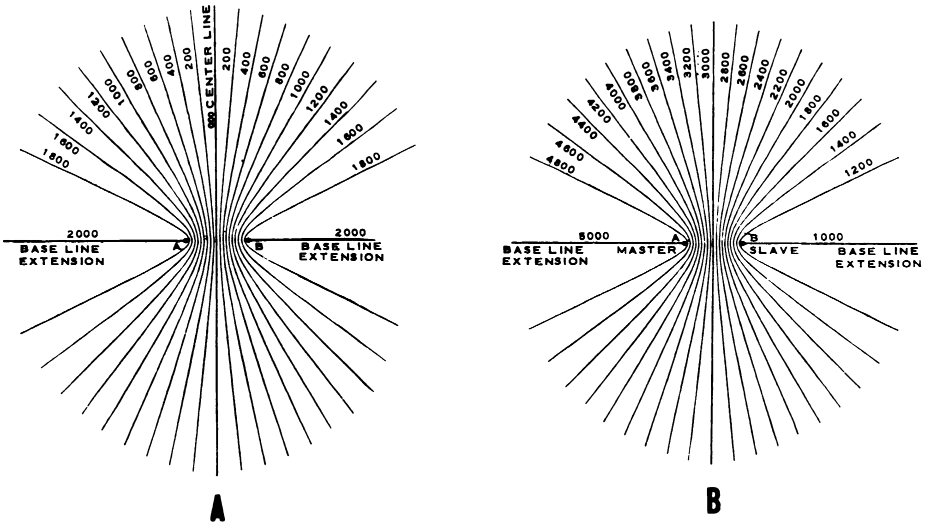

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Figure 17-14.—Lines of position. (A) No time delay. (B) 3,000-microsecond delay.

extension beyond the master station and minimum on the baseline extension beyond the slave station.

LORAN NAVIGATION

The loran navigation network is designed to cover a vast ocean area. This fact, coupled with the long distance usage, requires a fairly large number of stations. However, loran stations operate in a crowded portion of the radio spectrum; therefore, only a few specific frequencies are available. At the present time, only 3 channels are used, but as many as 24 station pairs may be operated on each. This is made possible by using a different pulse recurrence rate for each station pair on any channel. The equipment can thus distinguish between various pulse pairs and measure the time interval for any selected pair—Other pulse pairs are not synchronized with the CRT sweep, and therefore drift across the screen.

In order to determine a position by loran, it is necessary to obtain intersecting lines of position from two or more station pairs, then refer to a special loran chart to locate the position of that intersection.

The U.S. Navy Hydrographic Office publishes loran charts (which are standard Mercator charts with loran lines of position superimposed). The use of the chart in obtaining a "fix" is illustrated in figure 17-15.

A loran chart shows the lines of position of one station pair crossing those of another. In many installations, the two pairs consist of a single master station operating in conjunction with two slave stations. This is called double-pulsed transmission and is the type represented in figure 17-15. The common master station emits two sets of pulses. Each set is synchro-

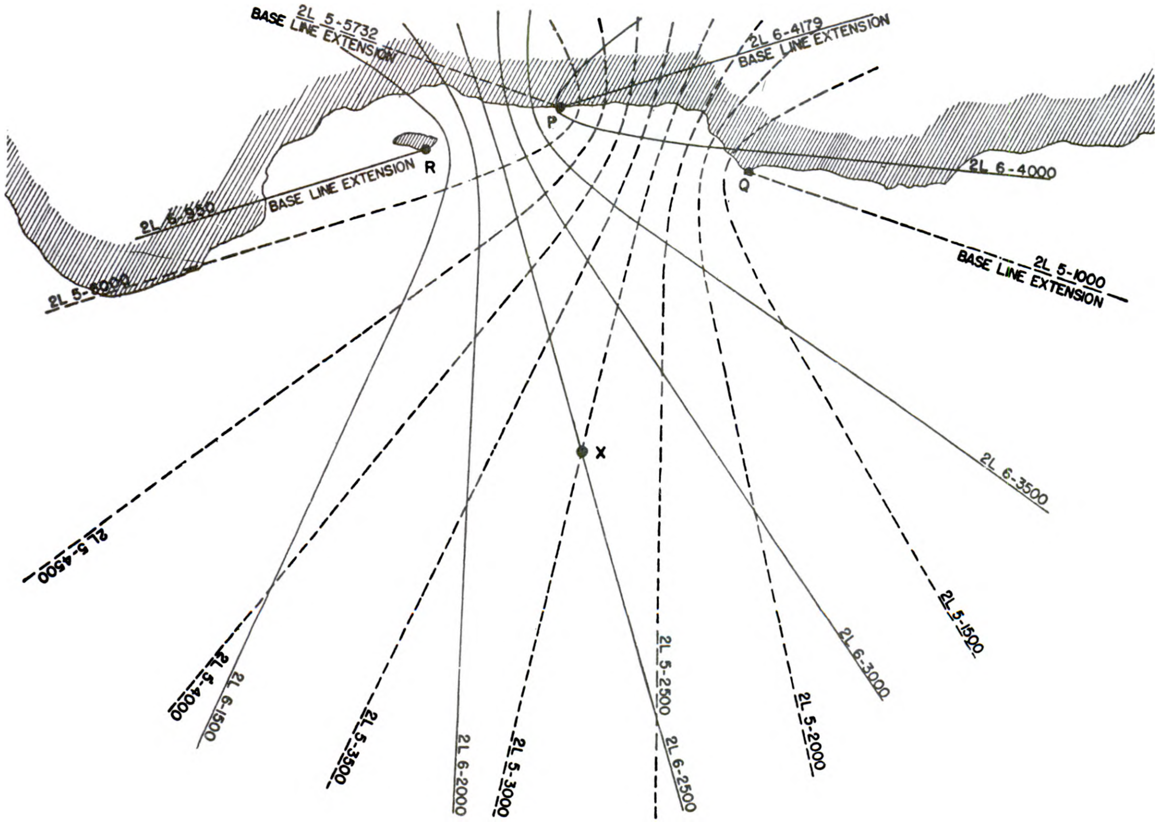

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Figure 17-15.—Obtaining a loran fix.

nized with one of the adjacent slave stations. In the figure, the master station is labeled P, and the slave stations are labeled R and Q. The combination P-R operates with a pulse recurrence rate that is different from the combination P-Q. Two families of lines are available, and the fix is made by taking measurements on both pairs, locating the observer at point X.

When loran fixes are made, the general location is usually known. The navigator consults the loran chart for that particular area and selects a station pair by setting the receiver controls according to the symbols given on the chart. The principal receiver settings are for channel frequency, basic pulse recurrence rate (high or low), and specific pulse recurrence rate. These required settings are indicated by the letter-number groups noted on each line of position. The last part of the group is the time difference (in microseconds) for that line of position.

LORAN AIRBORNE EQUIPMENT AN/APN-70

Receiving Set AN/APN-70 is an airborne navigational aid used to receive and interpret loran signals. It is installed in patrol, transport, and other long range aircraft. It is designed to operate over the standard medium frequency loran band from 1.7 to 2 MHz, and on the two low frequency channels from 90 to 110 kHz and 170 to 190 kHz.

The AN/APN-70 receiver uses the same antenna used by other electronic devices (such as communication receivers) in the same aircraft. An antenna coupler serves to isolate the loran equipment and to prevent interaction with the other electronic systems which share the common antenna. In addition to isolation of the receiver, the coupler unit also provides a means of matching the unit to the characteristics of different antennas, for amplifying signals to which the set is tuned, and for attenuating unwanted reception. Four stages of amplification are contained in the antenna coupler together with the associated impedance-matching and attenuation circuits. One stage is used with the loran system.

Principles of Operation

The receiver gives a direct reading in microseconds of the indicated time difference between the arrival of the master and slave pulses received from the loran transmitting stations in use. To measure this time difference, a fixed reference (master pedestal) and a variable reference (slave pedestal) must be used on the CRT. Variable-delay circuits, which are mechanically connected to a crank on the front panel, are incorporated in the equipment to give a variable pedestal on the lower trace. The indicated time difference is obtained by placing the master pulse on the leading edge of the fixed pedestal of the upper trace and positioning the leading edge of the variable pedestal of the lower trace under the slave pulse. The elapsed time can then be read on the front panel from counters connected to the crank.

The receiver contains two delay systems, so one reading for a standard loran station pair can be retained while the second value from another station pair is being taken. If one delay system fails, the equipment is still usable, since the two time difference readings required for a fix can be obtained from the remaining operating delay system.

The AN/APN-70 equipment provides for simultaneous reception of two low frequency loran stations. In this type of operation, the two time difference readings corresponding to lines of position appear simultaneously on the revolution counter dials. The simultaneous readings are based on triad operations of the transmitters. The loran triad consists of a master station which controls two slaves. The master transmitter is pulsed at twice the recurrence rate of the slaves while the slaves emit pulses at the same recurrence rate. One pulse from each slave is sent during each recurrence period, L, and the master pulses occur at intervals of L/2.

The master pulses are called X and Z, and the slave pulses are known as Y and W. During reception of signals from triads, all four pulses appear on the indicator in the sequence X-Y-Z-W. In order that the pulses can be identified readily on the screen, the X pulse is followed closely by a "ghost," resulting in a double vertical deflection.

The two readings given by the revolution counters are plotted on loran charts and enable the operator to determine his location.

The electron beam in the indicator tube traces two time baselines, one above the other, as indicated in figure 17-16. Moving from left to right, the beam slowly traces the upper line in a period of time equal to one-half the pulse recurrence interval. It quickly retraces, jumping to the left and below. It then traces the lower baseline in one-half the recurrence interval before rapidly returning to the start of another top line.

The master station pulse is superimposed on the upper baseline, and the slave pulse appears on the lower. When the receiver is correctly adjusted, the station pulses are displayed above pedestals (rectangular deflections) in the time baselines. The pedestals indicate portions of the display which can be expanded and examined in greater detail for accurate measurement. The time difference to be measured is represented by the horizontal distance between the master pulse on the left and the slave pulse below it to the right. This method of measuring the time difference automatically cancels the fixed delay of one-half the recurrence rate by which the slave pulse was retarded during transmission.

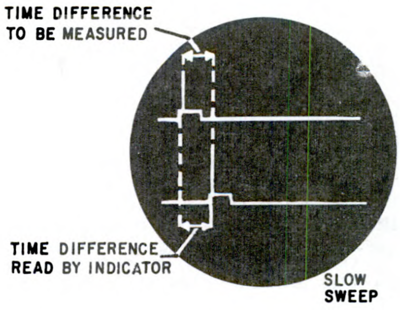

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Figure 17-16.–Time difference measured on a a loran indicator.

Theory of Operation

The APN-70 receiver assembly is composed of three major units: the RF receiver, the timer, and the deflection units. These sections are shown in block diagram form in figure 17-17,

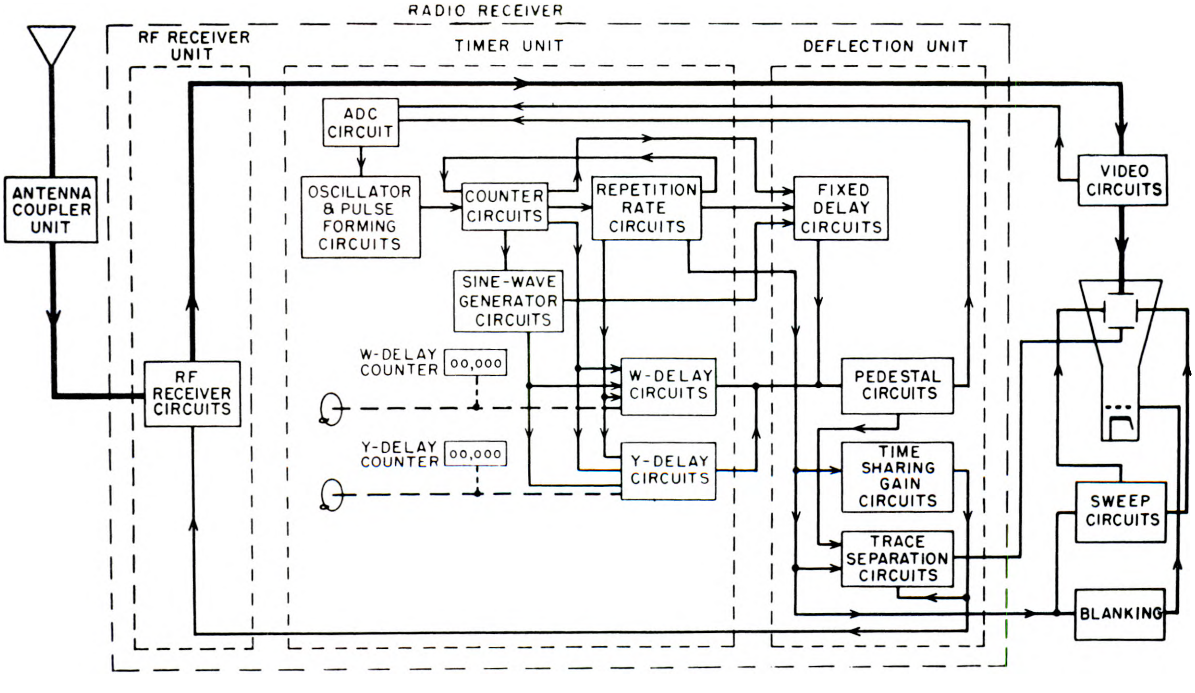

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Figure 17-17.–Receiver, AN/APN-70, block diagram.

which also includes the components of the loran indicator.

RF RECEIVER UNIT.–This portion of the loran receiver is a superheterodyne system, which contains an RF amplifier, a converter, two IF amplifiers, a detector, and a video amplifier. Loran signals are received from the antenna coupler by the RF amplifier, a tuned-grid, tuned-plate circuit. The output of the amplifier is applied to the converter stage.

One section of the converter stage is used as a crystal oscillator circuit that produces mixing voltages. The IF output of the converter, is amplified in the two IF amplifiers and fed to the detector. The resulting video pulses pass through one stage of amplification and are coupled through a cathode follower and the video section of the indicator to the vertical deflection system of the cathode-ray tube.

TIMER UNIT.–This unit generates a series of pulses serving as the time base of the equipment and produces the variable-delay intervals used to measure the time differences of the loran pulses. Also, to insure that the receiving set and the transmitter system are operating at the same recurrence rate, the timer contains circuits for synchronizing the two.

The timing standard in the receiver is an 80 kHz crystal oscillator from which is derived (either directly or indirectly) the time bases for the timer, delay, and deflection circuits. The oscillator is synchronized with the time base of the loran transmitter by the action of the automatic drift control circuits. The oscillator can be changed in frequency over a narrow range by a reactance tube whose d-c input grid voltage assumes a value corresponding to the degree of synchronism of the receiver circuits with the incoming loran pulses. The grid voltage of the reactance tube is produced by a discriminator tube which compares the repetition rate of the incoming master and slave pulses with the master and delay pulse pedestals from the receiver-indicator. (The master and delay pulses have a pulse rate set by the timer.) Any variation in the two rates produces a d-c bias on the control grid of the reactance tube which, in turn, corrects the oscillator frequency and the resulting pulse rate derived from it. Thus, automatic drift control is established.

The sine-wave output of the crystal oscillator is shaped to produce a sharp negative driving pulse which is applied to the counter circuits. The electronic counter contains 12 identical multivibrators and 10 identical interstage amplifiers. Each counter stage is a binary counter (divides the input pulse rate by 2). The first 11 of these stages, together with 10 interstage amplifiers, are used to obtain the repetition rate. The 12th stage is driven by the output of the repetition rate circuits to obtain a square wave which is equal to the recurrence rate of the loran transmitting stations selected.

The first multivibrator of the counting series is triggered by 80 kHz pulses derived from the pulse forming circuits. The output of the first stage is fed to the grid of the first interstage amplifier tube which drives the second multivibrator. This sequence is repeated throughout the first 11 stages so that the overall division ratio is 2,048 to 1; hence, the counter chain gives one output pulse for every 2,048 pulses fed into it when all 11 counters are used.

The repetition rate circuits accept the output of the counter section and produce the reset pulses which determine the time at which the counter stages reach the count selected by the position of the recurrence rate switch. At that time a pulse is generated to reset the counter chain for the next cycle and to drive the 12th stage. The position of the recurrence rate switch may be set for any one of the 24 loran repetition rates. In addition, the repetition rate circuits supply trigger pulses to the fixed-delay circuits, the time-sharing gain circuits, and to the sweep circuits in the indicator unit on position 1 of the function switch.

The W- and Y-delay indicating systems consist of dials, switches, gear trains, gating tubes, wave shapers, goniometers, pulse formers, and thyratrons. These systems are connected to stages 3 through 11 of the binary counter chain and to the 12th stage. Each delay system produces one output pulse during each L period. The occurence of this output can be varied uniformly and continuously (after the second reset) to start the succeeding loran cycle by means of a handcrank. Two dials indicate the microseconds of delay produced at the thyratron of each system. The W and Y systems are identical in construction and operation except that their outputs appear in successive L/2 periods for operation with low frequency loran signals (dual presentation). With high frequency (single presentation) loran reception, only one delay system operates, as determined by the setting of the W-Y switch.

DEFLECTION UNIT.–In addition to the low voltage power supply, the deflection chassis contains circuits that receive signals from the timer unit. These signals are used to synchronize and trigger waveforms that perform the following functions:

1. Generate three independent bias voltages for the three time-sharing gain circuits.
2. Generate waveforms to drive the sweep generator in positions 2, 3, 4, and 5 of the function switch.
3. Generate trace-separation waveforms when required by the function selected at the control panel.

In single presentation, the time-sharing gain controls enable the operator to adjust the receiver gain to an independent level on each trace appearing on the indicator screen. Either the W- or the Y-delay system may be independently selected by a control switch. In dual presentation, the delay reading and the gain setting of one pair of loran stations may remain on one counter dial and gain control knob while the operator is matching a second pair of loran pulses using the second delay system. The output of the time-sharing gain circuits supplies bias to the RF and IF stages of the RF receiver unit.

The trace-separation circuits are connected to the lower vertical deflection plate of the cathode-ray tube. The fixed-delay circuits provide a 1,625-microsecond delay for the trigger governing the appearance of the master pedestal. For dual presentation, one trigger signal for every L/2 interval is provided; in single presentation, only one trigger signal for every alternate L/2 is required.

The pedestal circuits receive pulses from the fixed-delay and variable-delay circuits and generate waveforms to produce the master and slave pedestals. The output waveforms are supplied by a cathode-coupled, one-shot multivibrator which provides a pedestal of approximately 400 microseconds in positions 3 and 5 of the function switch in single and dual operation. The pedestal is 1,200 microseconds long in position 1, 2, and 4 of the function switch in single operation, or 1,750 microseconds long in dual operation. In position 1 of the function switch, the multivibrator generates the pedestals seen on the traces on the indicator tube. In other positions of the switch, the pedestals are used to generate the traces, and only the video signals present during the portion of the pedestal covered by the trace are shown on the indicator tube.

LORAN INDICATOR.–As shown in figure 17-17, the loran indicator contains the sweep circuits for developing the horizontal deflection voltages, the cathode-ray tube blanking circuits, the video circuits, and the cathode-ray tube. In addition, the assembly contains two high voltage rectifiers which supply d-c potentials for the CRT.

The sweep and blanking circuits are triggered by the reset pulses from the repetition rate circuits on function 1 and by the pedestal generator circuits on functions 2, 3, 4, and 5. A horizontal sweep generator supplies a sawtooth voltage waveform that is applied to the left horizontal deflection plate of the CRT. A portion of the output is also fed to a phase inverter stage to give an output wave 180° out of phase with the sweep generator output and which is applied to the right deflection plate thus providing a push-pull horizontal deflection.

The blanking circuit extinguishes the electron beam in the indicator tube during retrace intervals in which the grid in the indicator tube is driven highly negative with respect to the cathode. A d-c restorer diode clamps positive swings of the CRT grid to the voltage set by the brilliance control and establishes the level about which blanking takes place. An RC combination in the blanking circuit insures that the traces seen on the screen of the indicator tube are delayed until after the start of the sweep to remove irregularities in the initial parts of the sweep cycle.

Video signals derived from the RF receiver unit are amplified in the video circuits and are applied to the upper vertical deflection plate of the CRT.

The d-c voltages needed for operation of the CRT are supplied by low voltage regulator power supplies in the receiver unit and by the two high voltage rectifiers in the indicator assembly. One high voltage rectifier produces a d-c potential of 1,300 volts, positive with respect to ground, which is applied to the indicator tube through a cap connection. The other high voltage supply develops 1,300 volts, negative with respect to ground, and is applied to the cathode of the tube.

AUTOMATIC RADIO DIRECTION FINDER

Automatic direction finders are radio receivers equipped with directional antennas which are used to determine the direction from which signals are received. Most units of this class provide facilities for manual operation in addition to automatic direction finding (ADF). The automatic mode involves the use of motor-driven antennas which are positioned by means of closed-loop control circuits.

Before the development of radar and loran, radio direction finding was one of the principal means for determining the position of aircraft in bad weather. When an aircraft is within reception range of a radio station, the ADF equipment provides a means of fixing the position with fair accuracy. In addition to its usefulness as a navigational aid, the automatic direction finder is also employed as one of the basic devices of electronic countermeasure systems.

BASIC PRINCIPLES

When a conductor is cut by magnetic lines of force, or lines of flux, a voltage is induced in the conductor. In order to cut lines of flux, the conductor must be perpendicular or must have a component that is perpendicular to the lines of flux; and the relative motion between flux and conductor must have a component in a direction that is perpendicular to both the lines of flux and the conductor.

A vertically polarized wave has a vertical electric (E) field and a horizontal magnetic (H) field; therefore, the wave induces voltage in vertical conductors only. A vertical wire, or monopole, is the simplest type of antenna. When a vertically polarized radio wave induces voltage in a monopole, the induced voltage is in phase with the incident wave and is the same for all horizontal angles of incidence. (See fig. 17-18.) This similarity of response pattern, in all directions simultaneously, suggests the name omnidirectional (omni means "all") for this type of antenna.

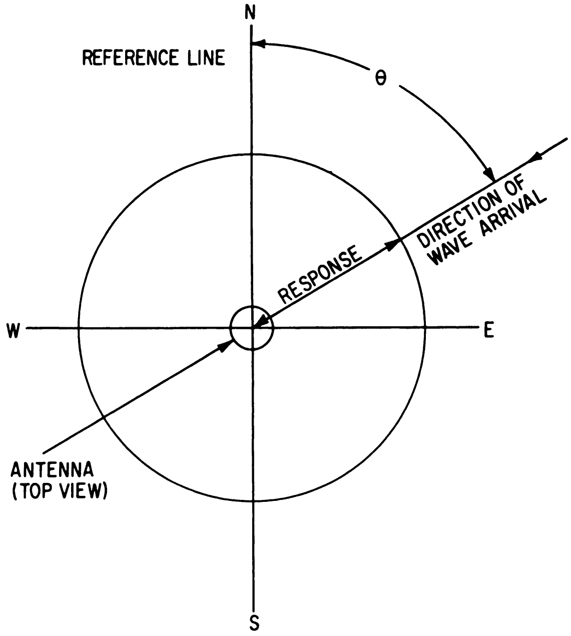

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Figure 17-18.—Polar response of a monopole (sense) antenna.

Loop and Sense Antenna

The response of a loop antenna is different from that of a vertical monopole (called a sense antenna in this discussion). A rectangular single-turn loop with dimensions that are small compared to the wavelength of an incident radiation field is shown in figure 17-19. As the loop is rotated about the axis XX', the angle θ (between the plane of the loop and the direction of propagation of the wave) is changed.

If the loop is placed in a radiation field like the one shown in figure 17-19, the H vectors of the field cut the sides AB and CD at slightly different times because the wave travels at a finite speed. At any instant, therefore, the voltage induced in arm AB is slightly different from the voltage induced in arm CD. (The arms BC and AD are not affected by the H lines of a wave polarized at right angles to them, and do not contribute to the induced voltage in the loop because the horizontal members are parallel to the H lines.)

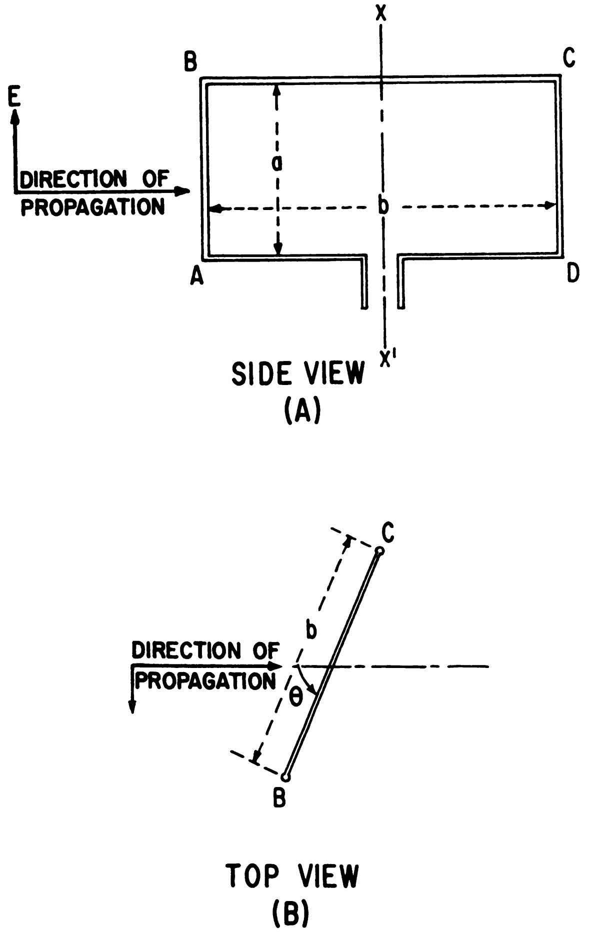

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Figure 17-19.—Loop antenna in a radiation field.

If the loop is turned so that its face is perpendicular to the direction of arrival of the wave—that is, $\theta = 90°$, the sides AB and CD are cut by the H vector at the same instant. The voltages induced in arms AB and CD are then the same magnitude and phase and neutralize each other, so that no current flows in the antenna loop.

Since the magnetic field of the radio wave alternates at the frequency of the wave, the instantaneous flux density at any point along the path of arrival varies sinusoidally. Thus the voltage induced into arms AB and CD are sinusoidal voltages with a phase difference θ. The total loop voltage is the sinusoidal voltage which represents the integration of the sums of all the instantaneous voltages induced into the two arms. It may be shown mathematically that this resultant voltage is proportional to the cosine of θ.

The pattern of the response is similar to the figure 8. (See fig. 17-20.) It is by using the response as shown in this figure that all medium frequency direction-finding equipments obtain bearings.

The directional characteristic of the loop antenna is called a cosine, or figure-of-eight pattern. When the loop is oriented so that the received signal is a maximum, a small change in orientation produces a small change in signal. However, when the loop is at a null position, a small change in orientation of the loop produces a large change in output voltage. Furthermore, there is a reversal in phase of the signal as the loop passes through a null point. For these reasons, the null points rather than the maximum-response points are used in radio direction finding to obtain a line bearing or line of arrival of a radio wave.

As there are two null positions 180° apart, the loop can give a line of bearing (the actual bearing or its reciprocal) but cannot determine the absolute direction of the transmitter from the direction finder. The determination of absolute direction, or sense, is obtained by adding the output of a vertical sense antenna to that of the loop antenna. When the two antennas are properly connected, the combined response is not ambiguous.

Signal Comparison

The figure-of-eight pattern of a loop has two null positions for one incident radio wave (fig. 17-20). If the outputs of a loop and a sense antenna are combined in phase, the response of the two antennas is the algebraic sum of their individual diagrams. In order to produce a

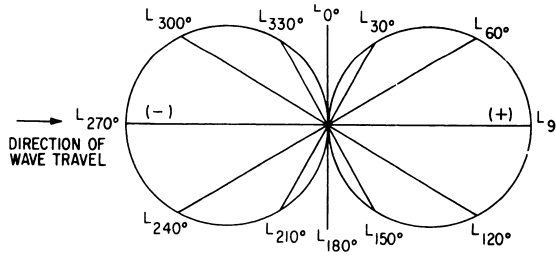

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Figure 17-20.—Polar response of a loop antenna.

given response, the magnitude of the individual signals must be considered. Refer to figure 17-21 for the following discussion.

This figure illustrates four possible responses caused by differences in the relative amplitudes of the sense and loop outputs. The desired response shown in (C) has one sharp null.

The output of the vertical sense antenna is independent of the horizontal direction of arrival of the wave, so it may be considered to have positive polarity. Because the phase of the loop voltage changes as the loop passes through a null, one-half of the figure-of-eight pattern may be said to have positive polarity and the other half to have negative polarity. The addition of the loop and sense curves gives the responses shown. The shape of the resultant curve is called a cardioid because of its similarity to a heart.

The output of the sense antenna is in phase with the radio wave. The output of the loop antenna, however, is 90° out of phase with the radio wave. This means that the loop output voltage is a maximum when the sense output is zero and vice versa. The cardioid pattern (which depends on the outputs being in phase) cannot be obtained unless the phase of either the loop or the sense antenna signal is changed by 90°.

The cardioid pattern produced by the combined loop and sense antenna can also be produced by the rhombic antenna. This type is used without a sense element.

DIRECTION FINDER SET AN/ARD-13

Direction Finder Set AN/ARD-13 is a low frequency radio navigation device that operates in the frequency range between 90 kHz to 1800 kHz. It is capable of receiving both AM and CW transmission within its operating range.

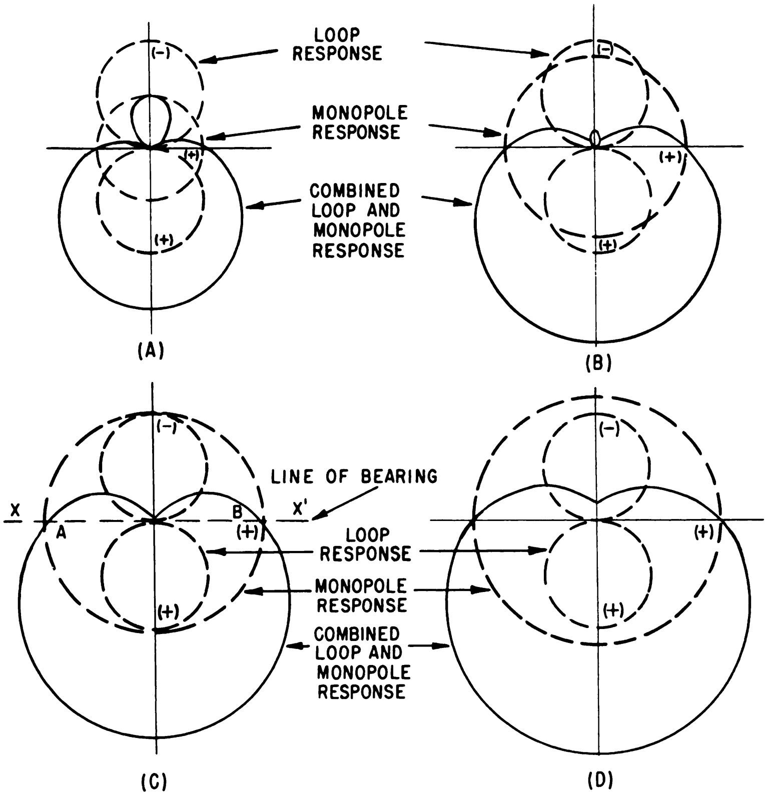

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Figure 17-21.–Response of the combined sense and loop antenna.

The direction finder has three modes of operation which are selected remotely at the control unit. In the ANT mode, the RF input to the receiver is from the sense antenna; the direction finder operates as a nondirectional low frequency receiver. The RF input in the LOOP mode is from the loop antenna. The LOOP mode may be used for manual direction finding by rotating the loop for an audio output null or a tuning meter null. (A 180° ambiguity in direction is possible in the LOOP mode since the loop antenna pattern has two nulls 180° apart.) The direction from which signals are best received can be chosen manually from the control box by positioning the loop. In the ADF mode, the receiver combines signals from both the sense and loop antennas to determine whether the loop is pointed to the left or to the right of the signal source. The receiver commands clockwise rotation of the loop if the loop axis is pointed to the left of the signal source. Counterclockwise rotation is commanded if the loop axis is to the right of the signal source. Rotation ceases when the loop axis is pointed directly at the signal source.

The position of the loop is continuously transmitted to the bearing indicator. The bearing indicator reads the bearing to the station in the ADF mode, because the loop is kept pointed directly at the station. The bearing indicator combines the bearing information from the direction finder with navigation data received from other equipment. Audio signals in all three modes are supplied to the intercommunication system in the aircraft. The audio level to the ICS is varied manually from the control box. (See fig. 17-22.)

Theory of Operation

ANT (ANTENNA) MODE.–Radiofrequency signals from the sense antenna are coupled to the RF amplifier through the impedance-matching network in the sense antenna couplet. The only signal input to the RF amplifier in the ANT mode comes from the sense antenna; the loop amplifier and the balanced modulator are disabled. The oscillator and mixer convert the output of the RF amplifier to 455.7 Hz, the intermediate frequency of the receiver. The oscillator is tuned from the control box by the tuning servo. One of two mechanical filters passes the desired signal and attenuates the undesired signals. The broad filter provides selectivity of 3.1 kHz, and the sharp filter provides receiver selectivity of 1.5 kHz. The narrow band output of the mechanical filters is amplified by the IF amplifier and is applied to the detectors. The output of one detector is used as the automatic volume control (AVC) signal to limit the gain of the RF and IF amplifiers. The AVC signal is also applied to the tuning meter. The output of the other detector is applied to the audio amplifier. The audio gain control is bypassed in ANT mode and manual control of receiver gain is with the RF gain control. The audio amplifier increases the output of the detector to the level required by the ICS in the aircraft.

LOOP MODE.–Rotation of the loop antenna is controlled by the LOOP switch on the control box. The LOOP switch applies either of two phases of 400 Hz a.c. from the receiver to the loop rotating motor in the loop antenna. In practice, the operator uses the LOOP switch to drive the loop antenna to the position of minimum reception of the received signal. This position of minimum reception, which occurs when the loop antenna is pointed directly at the signal source, is called the null position. The angle of the transmitting station, with respect to aircraft heading, can then be read accurately on the bearing indicator. The RF output of the loop antenna is applied to the balanced modulator through the loop amplifier. The balanced modulator is unbalanced during loop operation and couples the output of the loop amplifier to the RF amplifier. Signals from the balanced modulator are the only input to the RF amplifier in the loop mode. The input to the RF amplifier is the same as in the antenna mode operation.

ADF MODE.–The RF output of the loop antenna has either of two phases relative to signals from the sense antenna. Phase A, as shown, occurs when the loop antenna is to the right of the null position. Phase B occurs when the loop is to the left of the null. The loop antenna has no output when in the null position. Either output phase of the loop antenna is modulated by a 47 Hz signal in the balanced modulator stage. The results of modulation for either phase input are shown.

The output of the balanced modulator is added to signals from the sense antenna by the RF amplifier. Note that there is a 180° difference in phase between the envelope of A, present when the loop antenna is to the right of the null, and envelope B, present when the loop antenna is to the left of the null. The output of the IF amplifier is amplified and detected, and is applied to the audio amplifier. The output of the audio amplifier is processed and applied to the 47 Hz amplifier.

The amplified 47 Hz component of the output of the audio amplifier is applied to the discriminator. The discriminator compares the phase of the 47 Hz signal from the 47-Hz amplifier with the reference phase from the 47 Hz oscillator. If the two are in phase, the discriminator applies a positive d-c level to the 400 Hz modulator. If the two are out of phase, the discriminator applies a negative d-c level to the 400 Hz modulator.

The 400 Hz modulator applies either phase A or phase B 400 Hz signal to the loop servo-amplifier, which is connected to one winding of the loop antenna drive motor; phase A if the d-c level from the discriminator is positive, and phase B if the input from the discriminator is negative. Phase A causes the loop antenna to rotate to the left, phase B to the right. Thus, the signal that drives the loop antenna motor

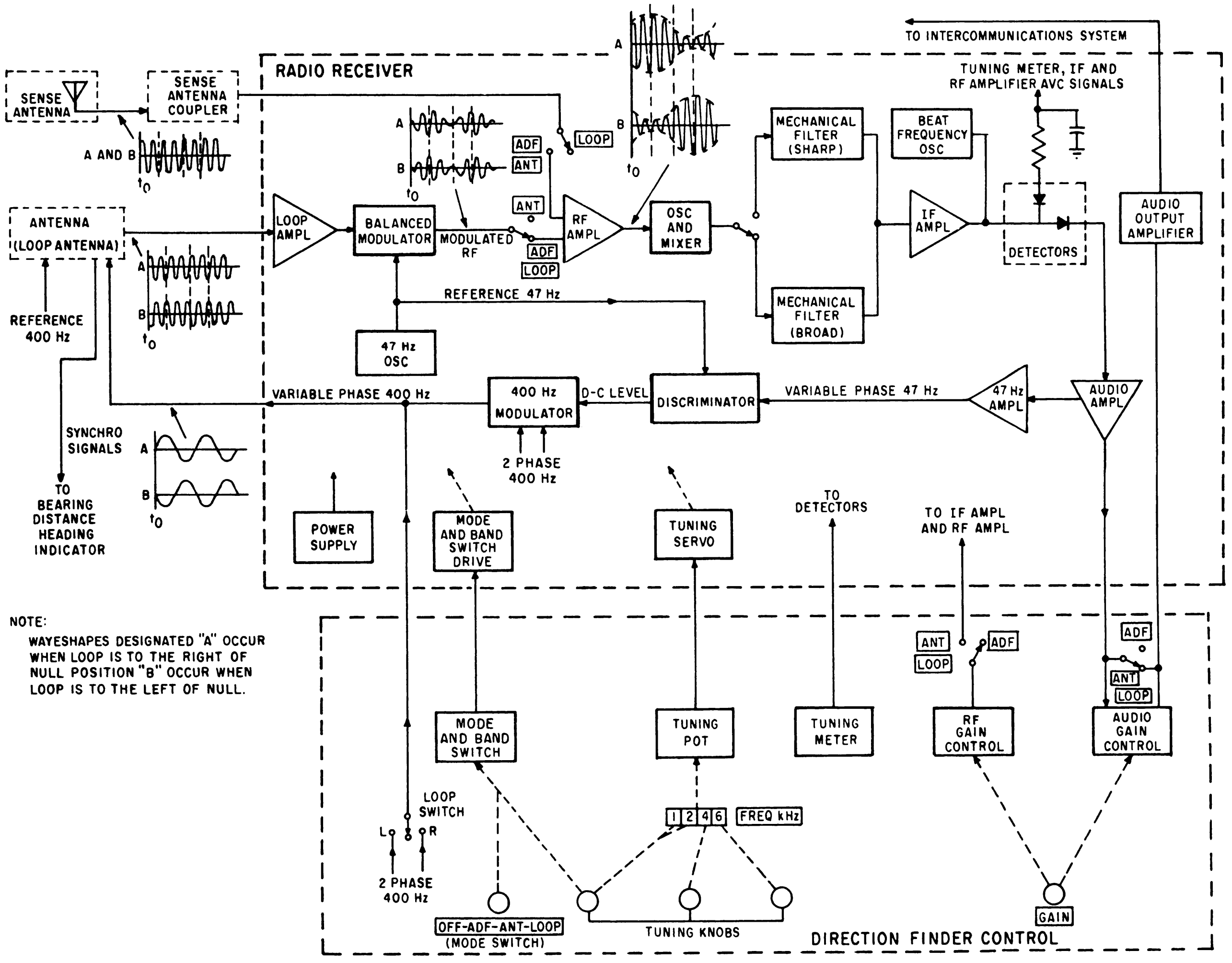

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Figure 17-22.—AN/ARD-13, simplified block diagram.

will always cause the loop antenna to rotate toward the null position.

The bearing indicator, electromechanically coupled to the loop antenna by synchros, reads the position of the loop and thus the direction to the signal source.

In the ADF mode, the RF gain control is inoperative. The audio gain control is used to vary the audio output level of the receiver.

ENVIRONMENTAL CONDITIONS

The environmental conditions under which an automatic direction finder must operate are important in determining the effectiveness of the equipment and the reliability of radio bearings. Satisfactory reception of radio signals depends on many factors. These factors may be broadly classified according to position, propagation characteristics, frequency characteristics, atmospheric conditions, and equipment capabilities.

Position

The farther a receiver is removed from the transmitter, the weaker the signal becomes. Pilots flying a radio beam sometimes use this gradual "fading" to determine the direction of the station. However, fading may result from many other causes, and is therefore frequently unreliable as an indication. In general, fading may result from the simultaneous reception of direct and reflected waves tending to cancel, thus decreasing signal strength.

Propagation Characteristics

A radiated electromagnetic wave tends to travel in a straight line, as discussed in chapter 5 of this manual. However, as discussed in chapter 9, there is a "bending" effect which occurs in radio wave travel. The actual amount of the bending depends on atmospheric density, temperature, and humidity. It is also affected by the electrical conductivity of the surface over which the wave travels.

In addition to the bending (refraction and diffraction), radio waves are also susceptible to reflection. Reflection may occur at the surface of the sea or land, from a mountainside, from ships, or from the ionosphere. It may have a relatively constant effect on the signal, or it may have a merely transient effect.

Some of the more important effects on radio wave propagation are the result of changes in the location and ionization of the ionospheric layer. This is discussed in basic form in Basic Electronics, NavPers 10087-B.

Night effect, occuring at both dusk and dawn, results from a shift in the ionospheric layer. At night, the height of the ionosphere is at a lower level with respect to the earth's surface than in the daytime. During the transitional intervals (dawn and dusk), the ionospheric layer bends as the height change progresses. This means that the radio waves strike the layer at a varying angle, and the reflection angle varies accordingly.

Shoreline effect results from variations of temperature and humidity and from differences in electrical conductivity between sea and land masses. The resultant changes in refraction affect the accuracy and reliability of radio bearings taken in this area.

Frequency Characteristics

As discussed in previous chapters of this course, the frequency of a radio wave affects its range, its propagation characteristics, and its susceptibility to interference. In general, range varies inversely with frequency—above some certain frequency limit, operational usage is limited to the line-of-sight range. Below that limit, the refraction index varies and the resultant maximum range is affected.

Atmospheric Conditions

In airborne applications, radio reception is affected by weather. In addition to the temperature, humidity, and density mentioned previously, reception is also affected by the electrical charge of the atmosphere. Lightning disrupts radiowave usage during the period of the flash for normal frequencies. Extremely high frequencies, however, may be usable in spite of lightning.

Two additional static disturbances are created as a result of the aircraft flying through the charged atmosphere. Precipitation static results when atmospheric particles strike the aircraft and create a static charge on the aircraft. Static discharge interference results when charges built up on the aircraft are discharged into the atmosphere. Normally, these conditions are relatively minor; but under certain atmospheric conditions, they may render the radio bearings unusable.

Equipment Capabilities

As with any type of electronics equipment, the actual effectiveness of the AN/ARD-13 depends on the design characteristics, the installation details, the qualifications of the operator, and the quality of the maintenance performed. Design features may eliminate many problems; but within the design limits of the equipment, maintenance and calibration determine its actual effectiveness. The maintenance practices and procedures, as prescribed in the appropriate technical manuals for the equipment and for the aircraft in which it is installed, must be adhered to.

CALIBRATION

The radiofrequency field pattern in the vicinity of the aircraft is distorted by the configuration of the aircraft itself. This distortion varies with respect to the earth's magnetic field, with the heading of the aircraft, and with the electromagnetic fields resulting from the operation of various equipment.

Although it is possible to compensate for many factors while on the ground, the final calibrations should be done in the air. It must be repeated when the operating area of the aircraft is changed. The procedure is elaborate and time consuming, but it is essential if the full value of the equipment is to be realized. For details concerning the calibration procedure, consult the appropriate volume of the Maintenance Instructions Manual for the specific model aircraft.

OTHER ADF EQUIPMENTS

AN/ARN-41A Direction Finder

Radio Receiving Set AN/ARN-41A is a combination automatic direction finder and radio receiver designed for use in aircraft. When signals from the sense antenna alone are selected, the equipment functions as a conventional radio receiver for continuous-wave and amplitude-modulated signals. When signals are selected from both the loop and sense antennas, the equipment functions as an automatic direction finder (ADF), providing automatic visual and aural indications of the relative direction from which radio signals are being received. The equipment frequency range is from 190 kHz through 430 kHz and from 480 kHz through 1,725 kHz. This is covered in three bands. The equipment may be used as an ADF or radio receiver on all its bands.

The AN/ARN-41A can be used for homing on a single station, or for triangulation position fixing using two or more stations, or for position fixing on a single station using any of the double bearing methods presently in use. Only ground waves of the transmitting station are used in ADF operation.

AN/ARA-25 UHF Direction Finder

The AN/ARA-25 is an ultrahigh frequency ADF that is used on most naval aircraft having UHF transceivers.

Desirable performance of the AN/ARA-25 and its relative freedom from serious maintenance problems, have proven it to be a reliable homing equipment. Accurate bearings on received signals at relative bearings of 000° and 180° are rapidly obtained; and while this is being accomplished, communication with the UHF Station is interrupted for only short periods of time. Bearings at other than 000° or 180° relative are not as accurate due to deviation.

The heart of the AN/ARA-25 ADF is the directional antenna. Because of the design of the antenna, no sense antenna is necessary. The AN/ARA-25 antenna is a flat, diamond-shaped (rhombic) plate placed over a tapered cavity. The cavity is designed to maintain a 50-ohm characteristic impedance at frequencies in the range of 225 MHz to 400 MHz.

BENCH TEST AND ALINEMENT

To either bench test or aline an ADF, the first consideration is whether the particular set is a complete receiver or an auxiliary piece of equipment. If it is an auxiliary equipment such as the AN/ARA-25 or AN/ARA-50, it must be placed in a bench set with the parent equipment. The parent equipment usually supplies the auxiliary with its power needs.

Normally there is no special test equipment needed that is peculiar to the ADF. Therefore, the important aspects of test equipment selection is the operating frequency of the ADF and test equipment, the type of modulation used by the ADF and test equipment, and the output signal of the particular ADF.

DOPPLER NAVIGATION SYSTEMS

Doppler navigational radar automatically and continuously computes and displays groundspeed and drift angle of an aircraft in flight without the aid of ground stations, wind estimates, or true airspeed data. This is done by utilizing auxiliary inputs from an altitude rate sensor and from the aircraft's vertical reference system. The Doppler navigation radar section does not sense range and bearing (direction) as ordinary search radar does. It employs continuous carrier wave transmission energy and determines the forward and lateral velocity components of the aircraft by utilizing the apparent frequency change phenomenon (Doppler shift) in the RF range.

The radar emits CW energy at one frequency; these waves of energy strike earth's surface and are reflected. Energy waves returning appear to be spaced differently than the waves that were transmitted.

The receiver of the Doppler radar system detects this apparent change in frequency; this is accomplished by use of two signal inputs—one from the transmitter and one from the receiver antenna. The input signal from the transmitter is at all times the same frequency as the signal being radiated; the receiver antenna signal frequency will vary with the relative speed. The two frequencies are compared in the receiver, and the difference frequency is a direct indication of the groundspeed of the aircraft.

An analysis of the Doppler shift, as it applies to RF frequencies, is presented in chapter 9 of this manual. Review of that material should prove helpful in understanding the discussions of actual Doppler radar navigational equipment.

TWO-BEAM SYSTEM (AN/APN-122)

One type of airborne Doppler navigation equipment is the AN/APN-122, an all-weather, self-contained system. It radiates two narrow, fixed beams of CW energy downward, outward, and rearward (thus the ground becomes an opening target) from the aircraft's longitudinal axis. The ground-returned energy is intercepted by the receiver and compared with the outgoing transmitter energy. The difference (due to the Doppler effect) is used to develop velocity component information for use in the computing section. The velocity component, with the aid of roll angle, pitch angle, and altitude rate data furnished from auxiliary equipment, derives the groundspeed and drift angle in the computing section.

The groundspeed and drift angle information is continuously displayed on an indicating dial. It is also made available as a continuous synchro output signal for tie-in with other navigational equipment—position computers, bomb directors, and/or integrated flight director systems.

Operating Principles

The receiver-transmitter unit, shown in figure 17-23, consists of a Fiberglas paraboloid which contains a waveguide assembly, two crystal mixer assemblies, and a klystron oscillator assembly. The inner surface of the paraboloid is sprayed with a metallic reflecting material. As well as serving as a container for the various units, the paraboloid also serves as the transmitting and receiving antenna. The paraboloid is divided in the center by a wall called the septum, in which the waveguide is mounted.

The transmitting waveguide originates at the klystron and is a T-shaped section terminating in two transmitting horns (only one transmitting horn is visible in figure 17-23). Two receiving waveguide sections are attached to the transmitting section. They have crystal mixer cavities mounted at the upper ends, receiving horns at the lower ends, and coupling slots provided between each receiving and transmitting section.

The klystron, mounted at the center of the waveguide, receives d-c filament and cathode power from the high voltage power supply and

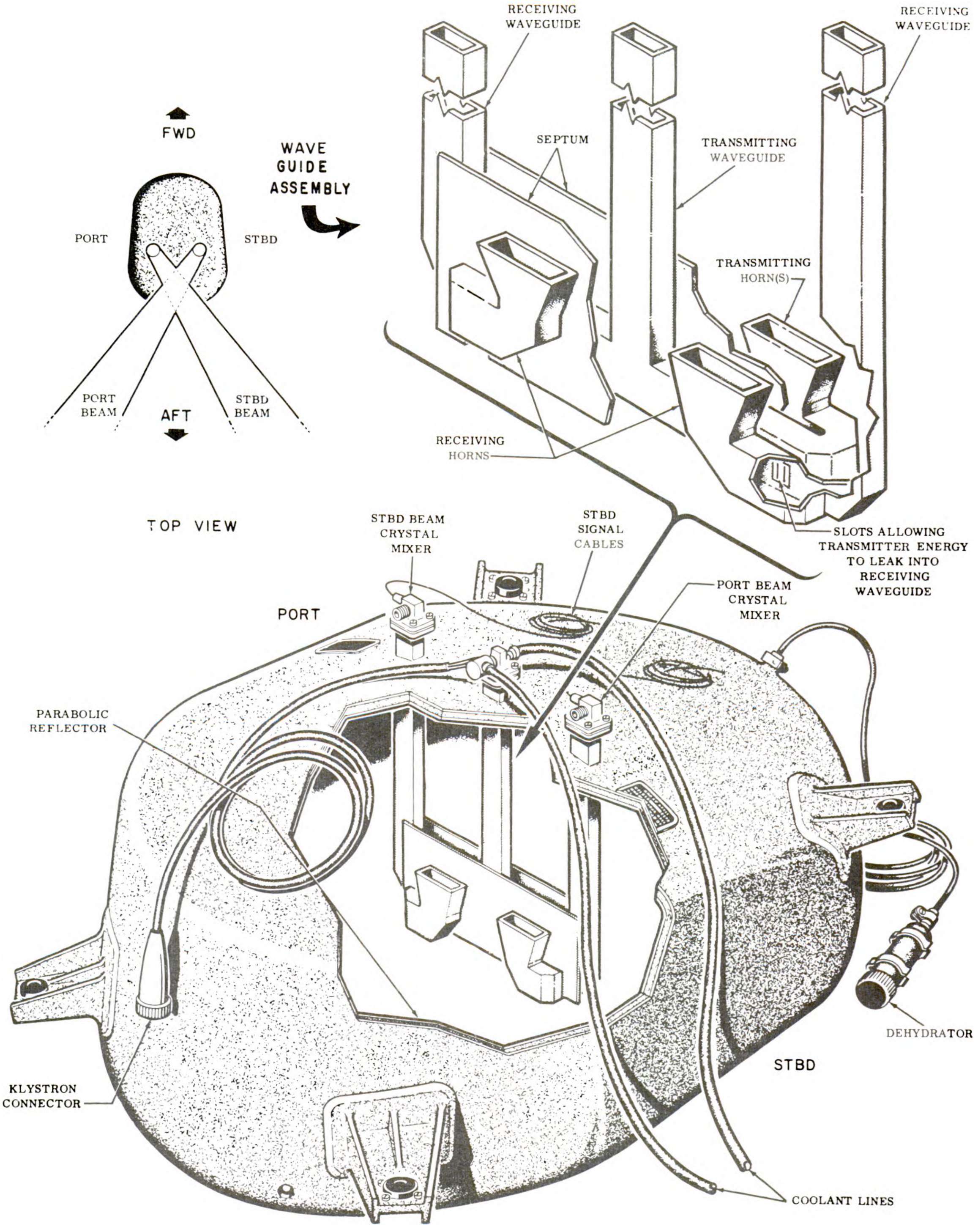

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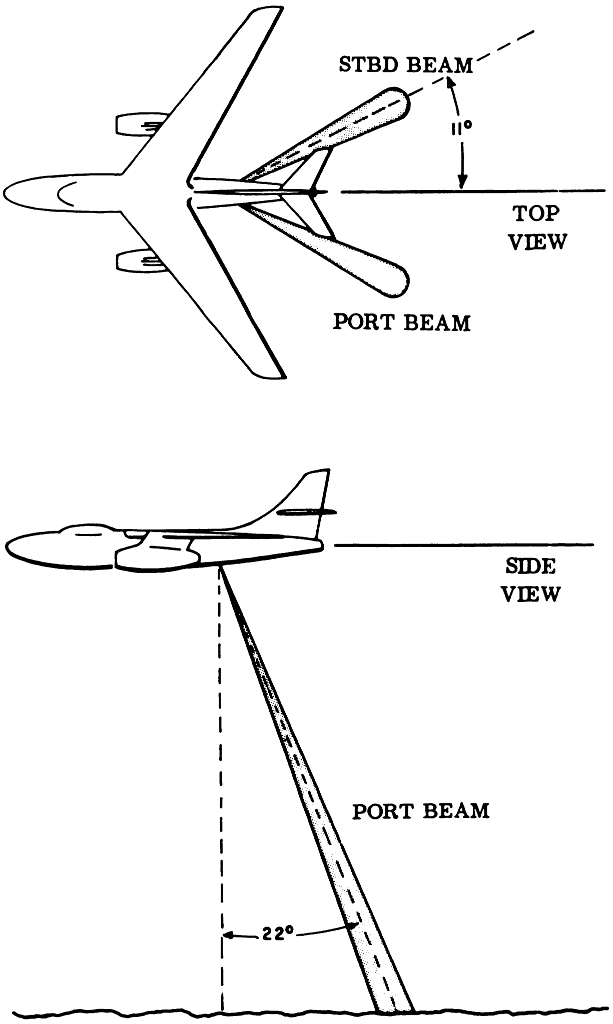
Figure 17-23.–Receiver-transmitter unit, mechanical assembly.

liquid coolant from the electron tube liquid cooler. The klystron is a dual cavity resonator. The CW energy from the klystron cavity is coupled to the waveguide through an impedance matching aperture located in the end of the waveguide, and through a coupling choke built into the waveguide flange. The energy is coupled down through the waveguide to the T-section where a power divider sends half of the energy to each transmitting horn. The power divider is a small probe located across the waveguide at the center of the T-section.

The reflecting surface of the antenna dish concentrates the energy into two narrow beams on opposite sides of the aircraft. These beams are directed outboard and downward to the rear of the aircraft, as shown in figure 17-24. The beams are directed outboard from the aircraft through an angle of 11°; simultaneously, they are directed aft through an angle of 22°.

Although the angular width of the radar beam is narrow, its linear width increases with increasing distance from the aircraft. As a consequence, the angle of incidence of different parts of the beam and the direction of the energy reflected from the ground vary. Specifically, the result is that the energy striking the ground at the steepest angle relative to the longitudinal axis of the aircraft returns at the highest frequency, producing the lowest Doppler frequency; and the energy striking the ground at the flattest angle returns at the lowest frequency, producing the highest Doppler frequency. There will be a general frequency band or spectrum between these two Doppler frequency extremes, and the energy transmitted at the center and received from the center of the radiation lobe will be at the greatest power and at approximately the center frequency of this band.

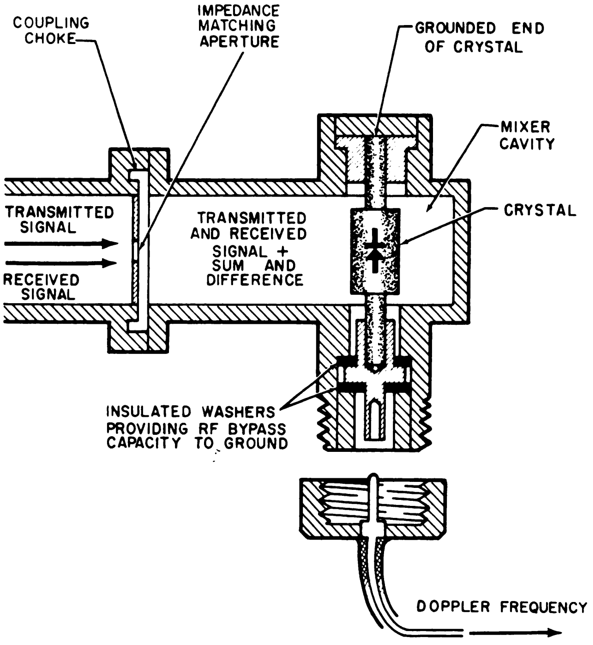


AT.327

Figure 17-24.—Radar beam orientation.

The reflected energy is picked up by the receiving half of the antenna and focused into the receiving horns. This energy is directed through the waveguides to the receiving crystal mixer cavities. The impedance of the waveguide is matched to the crystal mixer by a matching aperture located at the coupling flange. The flange also contains a coupling choke to prevent loss of energy at this junction. A sampling of the transmitter's energy leaks into the receiving waveguides through two narrow coupling slots between the two sections of the transmitting and receiving waveguides. (See fig. 17-23.) These coupling apertures attenuate the transmitted energy so that only a small portion of its power is supplied to the receiving waveguide.

The crystal is placed across the cavity at a voltage point, as shown in figure 17-25, and functions as a pickup probe and as a mixer. Both the transmitted and received signals appear across the crystal; and since it is a nonlinear device, mixing action results. The sum and difference, and each of the two output frequencies, appear across the output of the crystal, but the sum and the two input frequencies are


COUPLING CHOKE
IMPEDANCE MATCHING APERTURE
GROUNDED END OF CRYSTAL
MIXER CAVITY
CRYSTAL
TRANSMITTED SIGNAL
RECEIVED SIGNAL
TRANSMITTED AND RECEIVED SIGNAL + SUM AND DIFFERENCE
INSULATED WASHERS PROVIDING RF BYPASS CAPACITY TO GROUND
DOPPLER FREQUENCY

AT.328

Figure 17-25.—Crystal mixer assembly.

shunted to ground by the capacities formed by the vinyl insulating washers supporting the crystal at its output end. The output from each crystal mixer is a Doppler frequency proportional to the velocity along its respective beam (port or starboard). (See fig. 17-26 (A).) If the aircraft is drifting in the port direction (fig. 17-26 (B)), the Doppler frequency output of the port crystal mixer will be lower than the output of the starboard crystal mixer. If the aircraft drifts toward starboard, the output of the starboard mixer will be lower. The difference or Doppler frequency is within the audio spectrum.

Equipment Theory

Figure 17-27 shows a simplified block diagram of the AN/APN-122 system. The receiver-transmitter unit operation was discussed previously. The audiofrequency Doppler shift signal is coupled from each crystal to the amplifier assembly.

The port and starboard signals are amplified by separate channels and then routed to the signal data converter. As soon as satisfactory acquisition is made of the center Doppler frequencies in the search mode, the circuitry automatically switches to the track mode. Two voltages are produced—analogs of the center Doppler frequency of each channel (port and starboard)—and represent the velocity component of aircraft motion measured in the direction of the two radiation beams. (The average signal represents the velocity along the fore and aft axis, while the difference between the two signals represents the side to side velocity.)

A memory circuit is included to maintain track in the event of momentary loss of signal. The analog voltages are routed to an electromechanical analog computer. The computer converts the signals (which are proportional to the aircraft's velocity components relative to the radar beams) into potentials representative of the heading and drift velocity components of the aircraft. The resultant groundspeed and drift angle information is displayed on an appropriate indicator.

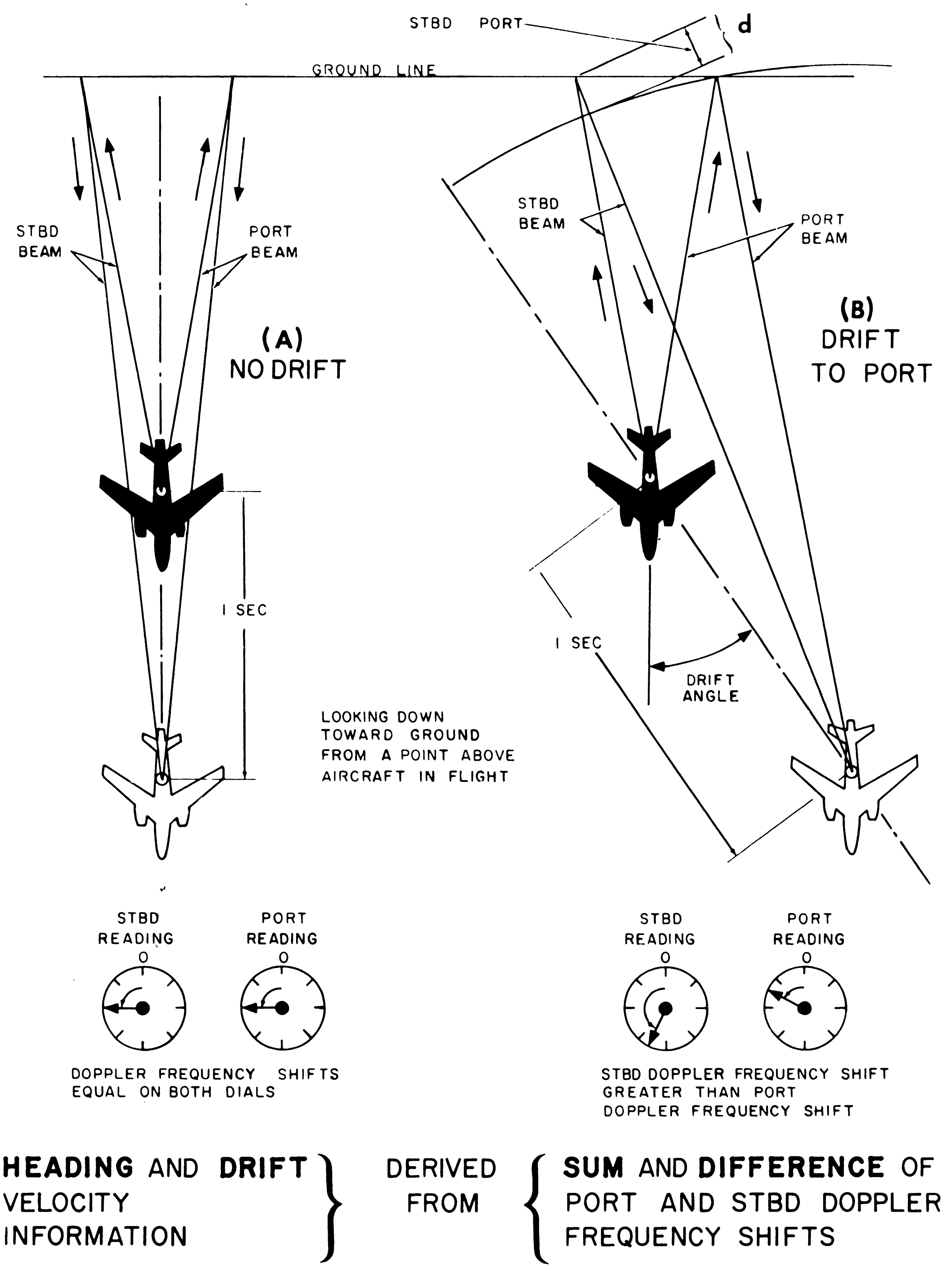
FIXED-WING SYSTEM (AN/APN-153)

The AN/APN-153(V) is a lightweight, miniaturized groundspeed and drift angle measuring system which is designed to satisfy the navigational requirements of modern military fixed-wing aircraft. It uses Doppler pulsed radar techniques to measure groundspeed and drift angle directly, continuously, and accurately. It operates anywhere, is relatively unaffected by weather conditions, and is independent of ground-based navigational aids. Its small size and light weight permit it to be easily installed in almost any fixed-wing aircraft.

The radar's groundspeed and drift angle data, together with aircraft heading data from any standard compass, are used to compute an aircraft's track projected on the ground. Using this information and conventional dead reckoning techniques, a pilot can navigate accurately over long distances.

Application

Groundspeed and drift data, in addition to being presented on a counter and dial, are available as electrical outputs. These outputs


STBD PORT
d
GROUND LINE
STBD BEAM
PORT BEAM
(A)
NO DRIFT
1 SEC
LOOKING DOWN TOWARD GROUND FROM A POINT ABOVE AIRCRAFT IN FLIGHT
STBD BEAM
PORT BEAM
(B)
DRIFT TO PORT
1 SEC
DRIFT ANGLE
STBD READING
PORT READING
0
0
DOPPLER FREQUENCY SHIFTS EQUAL ON BOTH DIALS
STBD READING
PORT READING
0
0
STBD DOPPLER FREQUENCY SHIFT GREATER THAN PORT DOPPLER FREQUENCY SHIFT
HEADING AND DRIFT VELOCITY INFORMATION
DERIVED FROM
SUM AND DIFFERENCE OF PORT AND STBD DOPPLER FREQUENCY SHIFTS

AT.329

Figure 17-26.–Doppler frequency shift–effect of shift on dual beams.

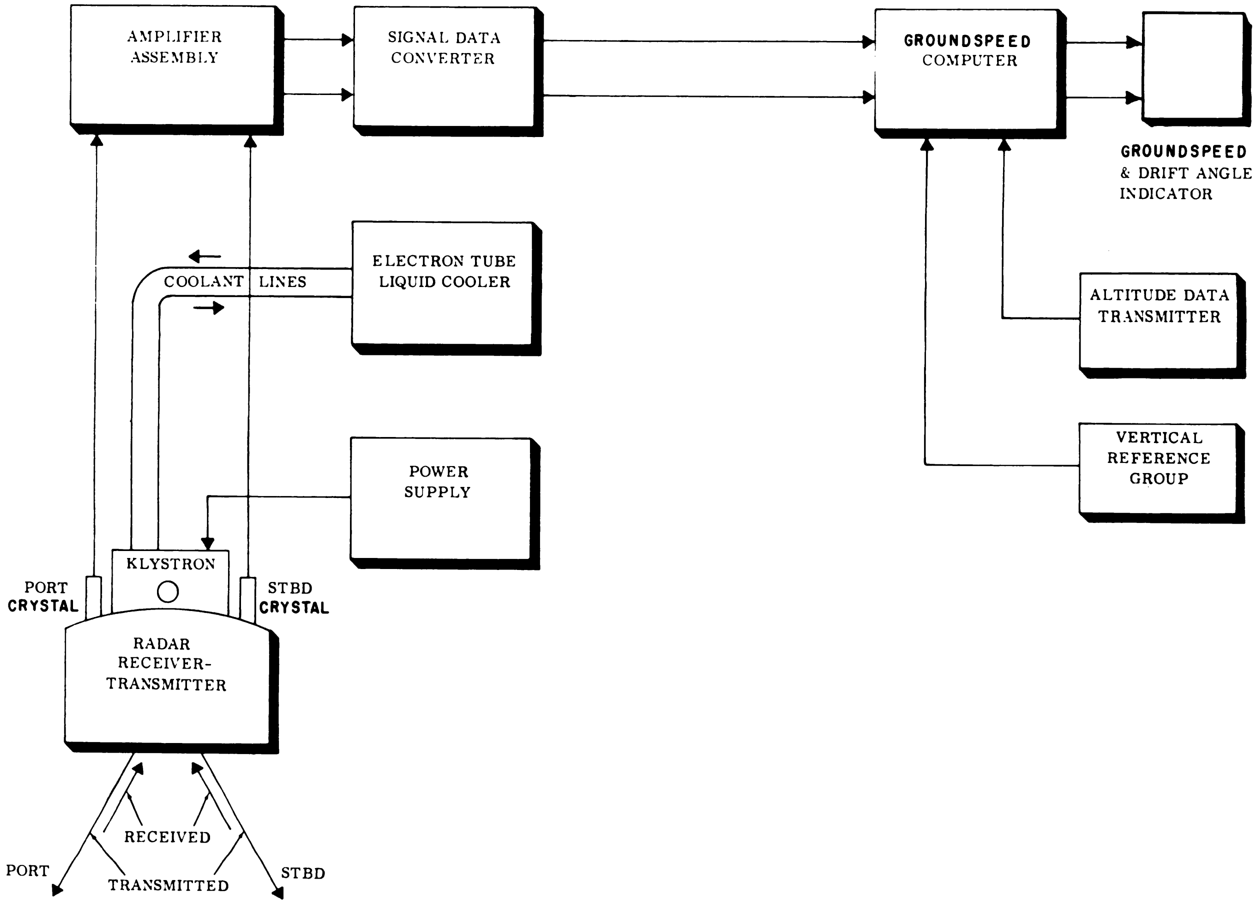


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Figure 17-27.–AN/APN-122, simplified block diagram.

can be fed automatically and continuously to navigational computers, mapping cameras, search radars, or other equipment which ordinarily utilize manual inputs of equivalent information.

A particularly useful application of the AN/APN-153(V) is its interconnection with various dead reckoning navigational computers, such as the AN/ASA-13A. Without the aid of a groundspeed and drift angle measuring system, navigational computers are sharply limited by the accuracy of the input information. The input data may consist of windspeed and direction, true airspeed, and aircraft heading. Only aircraft heading is usually obtainable with any high degree of accuracy.

Interconnection with this type of computer provides an automatic navigator which presents the aircraft's position with extreme accuracy. It is not limited by the accuracy of either available wind information or true airspeed data. The groundspeed and the drift angle are measured data and include the effect of wind. Thus, during normal operation, groundspeed and drift angle data need only be supplemented by aircraft heading data for continuous and automatic computation of the aircraft's position (given certain initial conditions).

Operating Principles

The AN/APN-153(V) emits short pulses of microwave energy, so the transmitter is not operative while an echo is being received. Therefore, in a single-beam radiation pattern there would be no second frequency with which to compare the echo. However, two beams—one projected dead ahead and the other directly behind—would experience equal but opposite Doppler shifts. In this event, one-half the difference between the two echo frequencies is the Doppler shift of either beam, and is proportional to groundspeed. This condition assumes no drift. If drift were present, the two-beam system described above would not detect it when used with pulsed beams. Antennas radiating to the left and right would detect sideways motion, but not fore and aft motion.

In order to make simultaneous measurement of both groundspeed and drift angle, the AN/APN-153(V) uses a modification of the two-beam pattern. The vicinity of the aircraft is divided into four quadrants—left forward, left rearward, right rearward, and right forward. (See fig. 17-28(A).) Simultaneous beams are radiated into diagonal quadrants, with switching of the quadrants at regular intervals.

When there is no drift, the ground track and aircraft heading coincide. In this condition, as shown in (B) of figure 17-28, the radiation pattern is symmetrical about the axes of the aircraft, and the left and right beams are at the same angle from ground track. The Doppler shift is equal in the beams.

When the antenna is not alined with ground track (fig. 17-28(C)), an angle exists between the antenna axis and ground track, and the beams experience unequal shifts. The difference frequency resulting from one pair of beams is higher than that from the other. As the switching action occurs, this difference is processed as an error signal which, through servo action, drives the antenna into alinement with ground track.

When the antenna is alined with ground track, the angle between the antenna axis and the aircraft heading represents the drift angle. Through a synchro system, this information is supplied to the computer along with the groundspeed data.

Advantages and Disadvantages

Due to its special radiation pattern, the AN/APN-153(V) is not affected by the vertical component of velocity which occurs during ascending or descending flight. Changes of altitude affect each beam equally, so the difference frequency remains the same. It is the difference frequency which is utilized to represent velocity.

Small roll and pitch angles of the antenna exist during normal flight. Roll angles introduce a greater shift into one beam and a smaller shift into the other, but the difference frequency is changed only slightly. Therefore, the inaccuracy of groundspeed measurements resulting from roll variations is very slight. Pitch angles do, however, cause inaccuracies which are significant. Therefore, the antenna is stabilized in its pitch axis to minimize pitch errors.

ROTARY-WING SYSTEM (AN/APN-130(V))

The AN/APN-130(V) is a four-beam navigation set which provides information for use in helicopter automatic navigation, as well as control during hovering and directional flight. This equipment is a representative advanced Doppler equipment used for measuring ground velocity components of helicopters and other air vehicles having hovering and negative speed capabilities. The set incorporates an antenna design featuring narrow beam widths, low sea effect errors, fully automatic navigate-hover transition, and automatic frequency trackers.

Operating Principles

The set employs four narrow beams of continuous-wave energy directed downward and outward, fore and aft, and in symmetrical configuration with respect to the aircraft, as shown in figure 17-29. Frequency shifts occurring in each beam are proportional to the components of aircraft velocity along the respective antenna beam. The frequency shifts, which are due to the Doppler effect, are detected by mixing a portion of the transmitting signal with the received signal and detecting the audio beat frequency.

After detection, the continuous Doppler audio signals are amplified and supplied to the signal data converter which converts the signals into voltages proportional to the aircraft heading velocity, drift velocity and vertical velocity. Outputs proportional to these voltages are provided in proper electrical form to drive the appropriate auxiliary equipment.

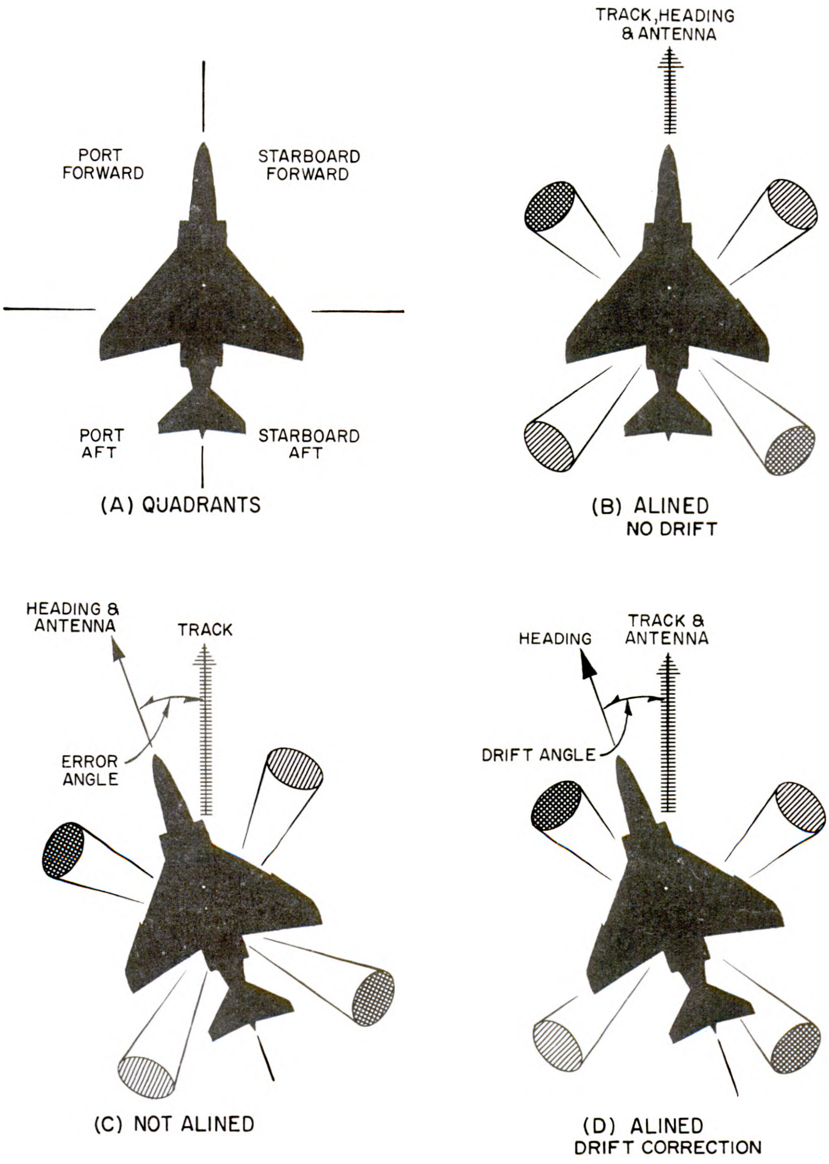

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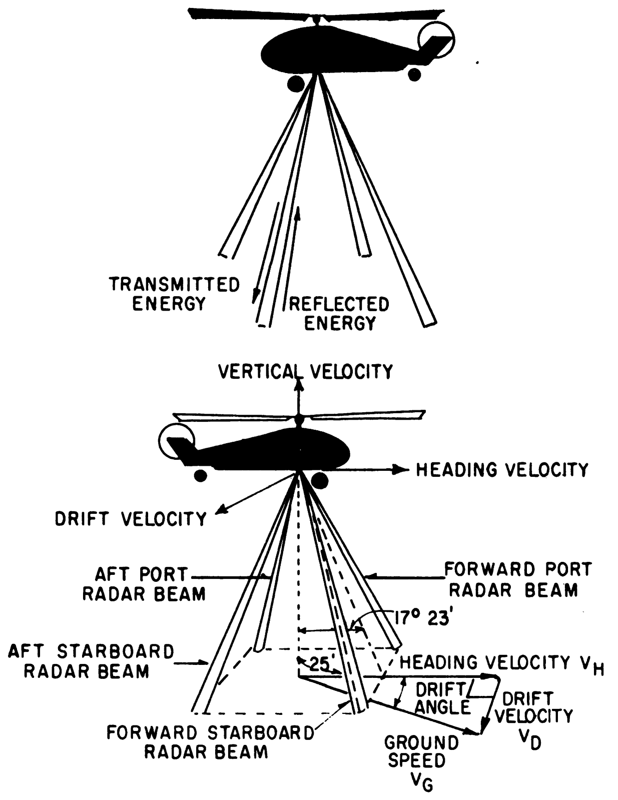
Figure 17-28.–Four beam pattern, using two-beam transmission.

Equipment Theory

The klystron tube in the radar receiver-transmitter generates continuous-wave RF energy at a frequency of 13.3 GHz± 5 MHz with a minimum power of 4.5 watts. The RF energy is coupled into the four transmitting wave guides and transmitted toward the earth in four narrow beams. A small portion of the transmitted energy is coupled into each pair of receiving waveguides through directional coupling slots spaced (electrically) 180° apart. (See fig. 17-30.) A portion of the transmitted energy is reflected from the earth to a parabolic reflector and into the four receiving horns. The RF energy for each beam is divided and coupled into two receiving waveguides for each beam. At this point, the two received



AT.332

Figure 17-29.–Antenna beam orientation.

signals for each beam are designated A and B. The configuration of the A and B channel waveguides is such that the A signal is shifted 1/4 wavelength or 90° from the B signal. The eight received signals are heterodyned with the transmitted signal at the crystal detectors. The eight low-level Doppler signals are fed to the amplifiers where they are amplified to a sufficient level for transmission to the signal data converter.

Four pairs of signal channels in the signal data converter receive the corresponding pairs of quadrature signals from the audio amplifier subassemblies of the radar receiver-transmitter. Each pair of signal channels corresponds to one of the four antenna beams. (See fig. 17-31.)

The signal data converter provides two basic modes of operation–hover and navigate. Transition between these two modes is automatic when the HOV/AUTO switch on the control-indicator is in the AUTO position. In the HOV position, all channels of the signal data converter are locked in the HOVER mode of operation. In the AUTO position, each channel pair is switched to either the HOVER or the OMNIDIRECTIONAL NAVIGATE mode independently of the other channels, or all channels may be switched simultaneously to the FORWARD NAVIGATE mode. The switching is controlled by the signal-to-noise density ratio and the frequency of the Doppler signal in each channel. A fail-save feature is provided wherein each channel is automatically switched from either of the navigate modes in the event that the Doppler signal is lost for a period exceeding approximately 2 seconds.

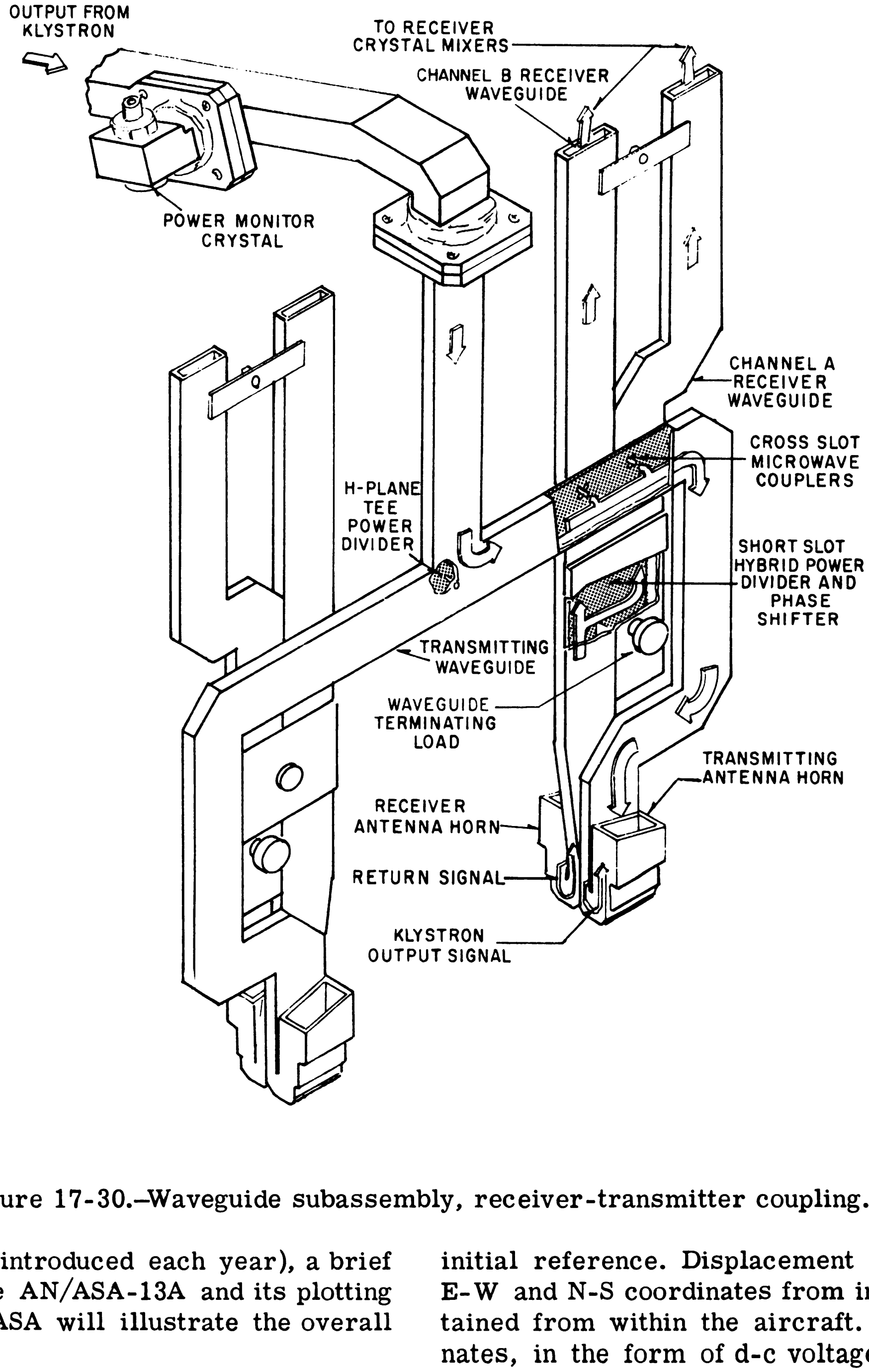
In fixed-wing aircraft, forward flight can be assumed. This is not logical in aircraft capable of negative velocities. Rapid direction sensing, as well as accurate velocity measurement, is extremely important for helicopter maneuvers at low velocities and during operations requiring hovering. The hover mode then requires coherent counting. Coherent counting, as used in this application, refers to the method used to develop an analog d-c output signal whose amplitude is proportional to aircraft velocity and whose polarity is an indication of aircraft direction. The Doppler signal in itself is not an indication of aircraft direction.

It is safe to assume that when a helicopter is traveling at some high rate of speed, the direction of flight is limited to forward flight with limited drift angle. Under these conditions, it is not necessary that each counter sense aircraft direction; therefore, the counters may operate in the noncoherent mode as long as the output polarities have been correctly established in velocity-sensing circuits.

ASSOCIATED EQUIPMENT

As mentioned previously, Doppler navigational radar equipment by itself cannot determine aircraft position or navigate the aircraft to a predetermined point. However, when used with associated navigational computers, these operations can be accomplished. The major function of the Doppler equipment is to supply extremely accurate data concerning velocity and drift angle.

Although there are many airborne navigational computers in use at the present time (and


OUTPUT FROM KLYSTRON
TO RECEIVER CRYSTAL MIXERS
CHANNEL B RECEIVER WAVEGUIDE
POWER MONITOR CRYSTAL
CHANNEL A RECEIVER WAVEGUIDE
CROSS SLOT MICROWAVE COUPLERS
H-PLANE TEE POWER DIVIDER
SHORT SLOT HYBRID POWER DIVIDER AND PHASE SHIFTER
TRANSMITTING WAVEGUIDE
WAVEGUIDE TERMINATING LOAD
TRANSMITTING ANTENNA HORN
RECEIVER ANTENNA HORN
RETURN SIGNAL
KLYSTRON OUTPUT SIGNAL

AT.333

Figure 17-30.–Waveguide subassembly, receiver-transmitter coupling.

more are being introduced each year), a brief discussion of the AN/ASA-13A and its plotting board OA-1768/ASA will illustrate the overall system.

The AN/ASA-13A

Navigational Computer Group AN/ASA-13A is an airborne dead reckoning computer which continuously determines displacement from an initial reference. Displacement is computed in E-W and N-S coordinates from information obtained from within the aircraft. These coordinates, in the form of d-c voltages, are used to displace CRT sweep origins for ground stabilized PPI displays.

The computer (fig. 17-32) resolves and combines voltages representing the airspeed and wind vectors. The resultant ground velocity (in component form) is then integrated to

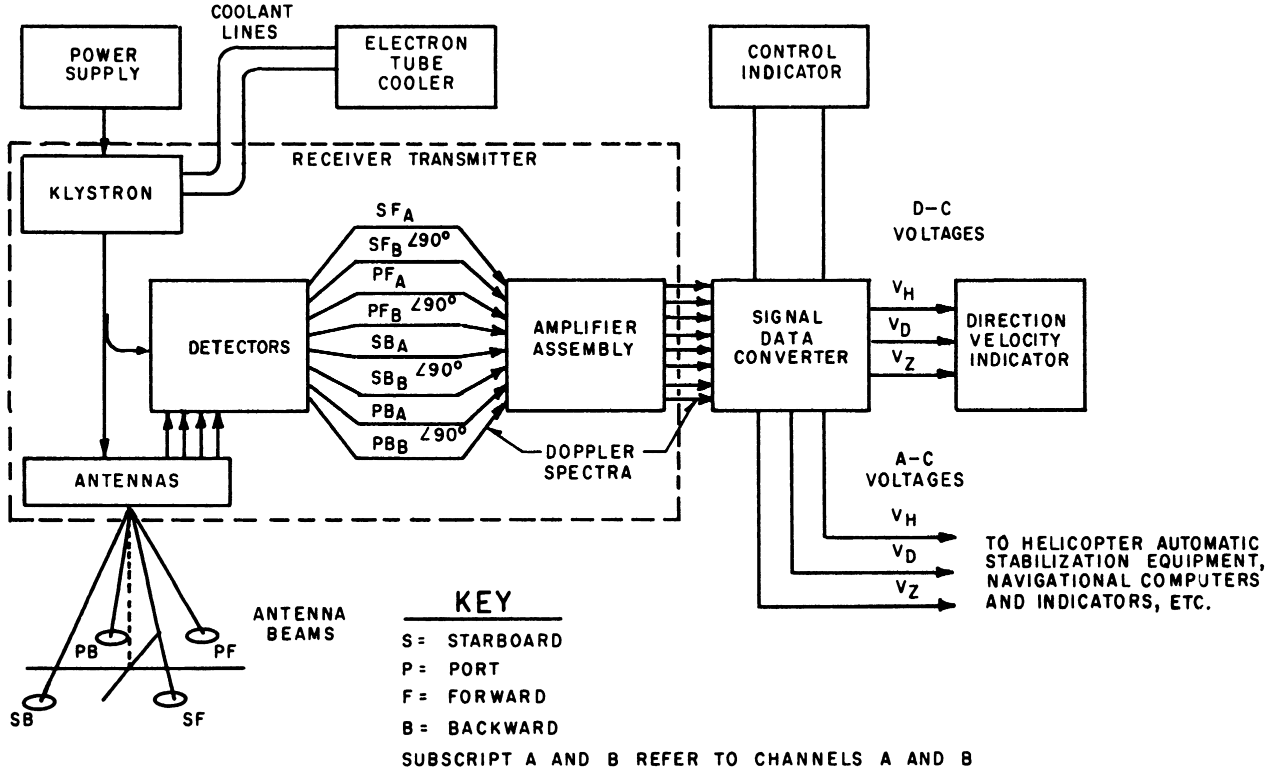


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Figure 17-31.–Functional block diagram.

provide an indication of N-S and E-W ground displacement (distance) from an initial reference point. Inputs of magnetic heading and pitot pressure are automatically and continuously supplied from aircraft instruments. By manually inserting local variation, magnetic heading is changed to true heading. Pitot pressure is converted to airspeed data. The airspeed vector, defined by airspeed and true heading, is resolved into N-S and E-W components. The wind vector is similarly resolved and combined with the components of airspeed to provide ground track data.

The wind vector may be obtained from the Doppler radar system (when operating) or from the Doppler radar's memory circuit (when not tracking), or it may be manually inserted when the Doppler radar is not operating.

The OA-1768/ASA-13

Display-Plotting Board Group OA-1768/ASA-13 is a short-range airborne navigational device used to display ground track of the aircraft and target position data. It is used in conjunction with the AN/ASA-13 or -13A and a search radar system to provide a readily available view of the overall tactical situation. It is used during ASW or AEW maneuvers to provide an accurate reference on which to base tactical decisions.

The plotting board may be used to indicate as well as record the following:

1. The position of the aircraft with respect to a preselected origin.
2. The position of a target relative to a remote reference point.
3. The present position of the aircraft and its position relative to the target.

The display, in the form of an illuminated arrow (called the crab), is continuously oriented to correspond to aircraft heading and ground track. The crab is driven by servomechanisms in response to N-S and E-W data supplied by the navigational computer.

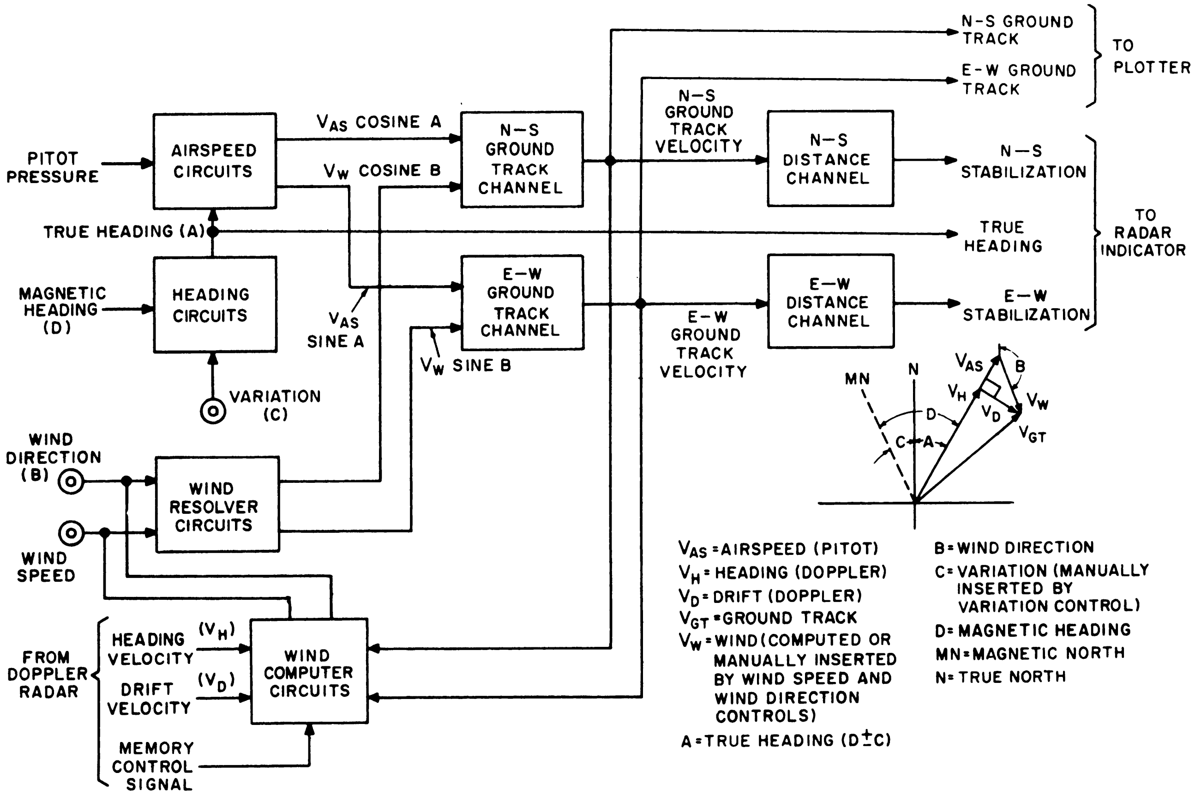

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Figure 17-32.–AN/ASA-13A, block diagram.

INERTIAL NAVIGATION

The introduction into the fleet of aircraft with inertial navigation systems (INS) has created a whole new set of problems for the maintenance technician, and emphasized some of the older problems. The use of INS has required increased utilization of gyros, accelerometers, synchros, servos, and other mechanical devices. It has also resulted in increased utilization of analog computers. When integrated with other equipment to provide a complete tactical system, it has also required the increased utilization of the digital computer. These individual topics have been discussed separately in previous chapters of this course. The remaining section of this chapter illustrates the combination of these components to form an inertial navigation system and indicates how the INS is utilized to provide data for inclusion into a complete tactical system.

BASIC THEORY

Inertial navigation is a type of dead reckoning. Equipments presently in use have very good accuracy, and this accuracy is being constantly improved through improvement of components and alinement techniques. Instead of measuring speed directly, the system derives it from measurement of the vehicle's accelerations. Two accelerometers are required–one referenced to north, the other referenced east. The accelerometers are mounted on a gyrostabilized unit (called the stable platform) to avert the introduction of errors resulting from the acceleration due to gravity.

Initial conditions are set into the system, and the navigation process is begun. The accelerometers sense accelerations in the N-S and E-W directions. These accelerations are doubly integrated with respect to time, and changes are continuously made to aircraft positional data.

NOTE: Integration and differentiation are specific types of mathematical computations, and are discussed in Mathematics, Vol. 2, NavPers 10071-B. In general, differentiation consists of breaking a relationship into small increments, while integration consists of combining increments into a larger idea. For example, in the relationship of acceleration, velocity, and distance, acceleration is a change in velocity per unit of time. Acceleration must be integrated with time (average acceleration multiplied by the time through which the acceleration is effective) to obtain the change in velocity. "Double integration" means that the first integral (velocity) must be integrated with time to form the second integral (distance).

STABLE PLATFORM

The stable platform (fig. 17-33) is attached to the vehicle through a gimbal system which permits it to assume any orientation with respect to the vehicle. In this typical system, three gyros are used, with their sensitive axes mutually perpendicular. The X-axis is oriented north and south, the Y-axis is oriented east and west, and the Z-axis is oriented perpendicular to both the other axes and in line with the earth's radius. Positive directions along the axes are defined as north, east, and toward the center of the earth. This terminology has been well standardized in all INS equipments.

Each gyro senses angular rate of displacement about its sensitive axis and precesses in accordance with the rate of displacement (as discussed in chapter 9 of this manual). It uses a pickoff unit to detect the precession in each axis and, through a servoloop, to drive a platform control torquer to null out the sensed rate and keep the platform "space stabilized" while the vehicle maneuvers about it. An additional correction is required to stabilize the platform with relation to the earth in order to eliminate errors of gravity. The method of compensating for this error is not discussed in this manual.

Displacement

As discussed in chapter 5 of this manual, motion of a body may be caused by either of two types of forces—contact forces or field forces. It is important to note that an accelerometer cannot distinguish between these forces. Newton's second law of motion describes acceleration force as follows:

The acceleration of a body is directly proportional to the magnitude of the applied force and inversely proportional to the mass of the body; acceleration is in the direction of the applied force.

It should be understood that the accelerometer will provide no output while it is moving at a constant velocity and its sensitive axis is perpendicular to the gravitational force. If the sensitive axis should become misalined, gravitational acceleration will result in a force which displaces the mass, causing the accelerometer to give an erroneous indication of the vehicle's acceleration.

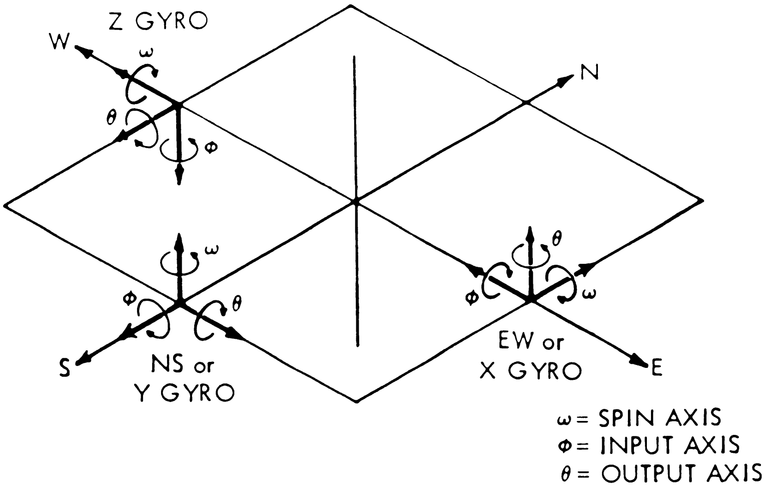
INITIALIZATION

In inertial navigation, the term initialization is used to denote the process of bringing the system to a set of initial conditions from which it can proceed with the navigation process. These conditions include leveling the platform, alining the azimuth reference, setting the initial velocity, setting the initial position, and making any computations required to start the navigation.

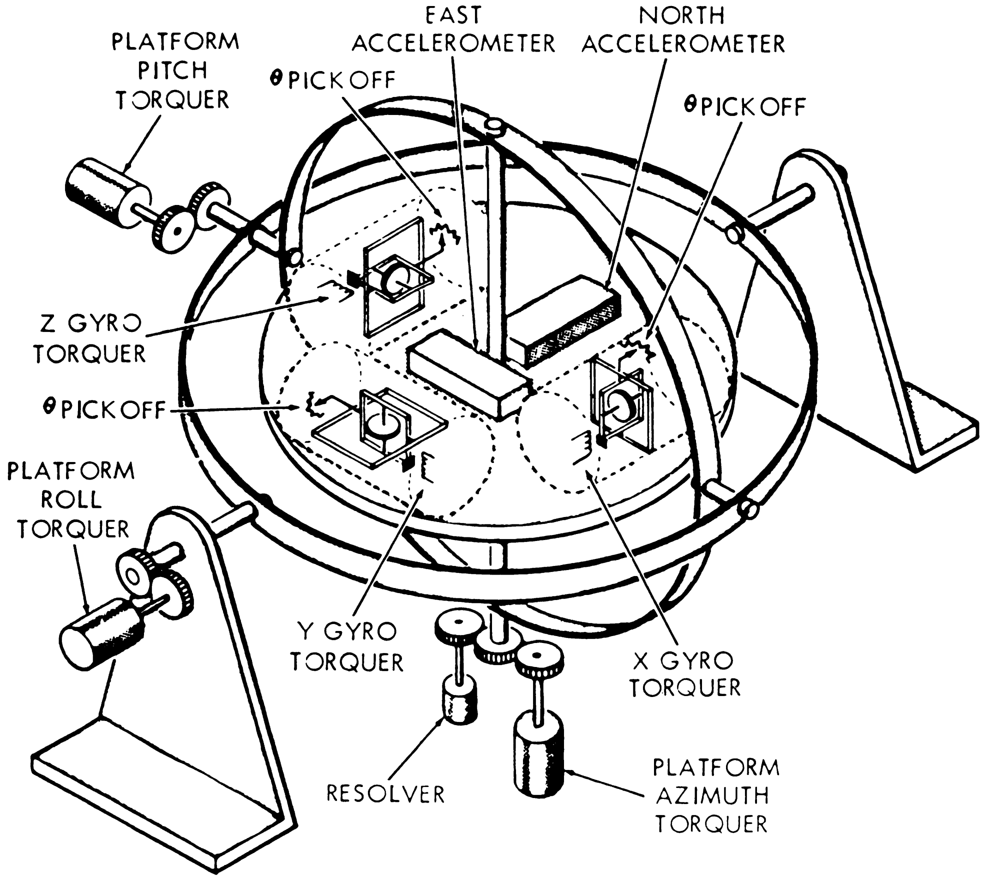
Failure to achieve the proper initial conditions is disastrous to navigational accuracy. Although all inertial navigation systems must be initialized, the procedure varies according to the equipment, the type aircraft in which it is installed, and whether the system is shore based or ship based. Initialization must be accomplished with great care and accuracy, and in strict accordance with prescribed procedures. These procedures are detailed in appropriate technical manuals.

INERTIAL NAVIGATION SYSTEM AN/ASN-36

The Inertial Navigation System AN/ASN-36 (INS) measures aircraft velocities in the north-south, east-west, and vertical directions. Aircraft pitch and roll data are furnished to associated flight systems and instruments for navigational computations and displays. Magnetic heading, true heading, heading error, and magnetic variation data are also generated and supplied. Indications of aircraft latitude and local



PLATFORM GYRO-VECTOR ORIENTATION



PHYSICAL ORIENTATION

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Figure 17-33.–Platform control components and gyro vector orientation.

magnetic variation are continuously displayed by the associated computer-indicator group.

Figure 17-34 comprises a simplified system block diagram of the AN/ASN-36 INS, showing inputs, outputs, and interconnecting signal paths.

In the normal INS operating mode, the navigation problem is continuously solved. Thus, aircraft true heading attitude (pitch and roll), and velocity data are provided continuously as INS outputs. Linear velocities of the aircraft relative to earth are obtained by intergration of the linear aircraft accelerations measured by the accelerometers.

To isolate these measurements from the effects of gravity accelerations, the system accelerometers are continuously maintained alined to earth-referenced spatial coordinates. This requires that the three accelerometers are mounted at right angles on the platform, and that the platform be maintained continuously perpendicular to the local gravity and alined in azimuth to true north. In the horizontal plane, sensed values of N-S and E-W accelerations are integrated, becoming linear velocities along these axes. Since the platform is maintained stable, aircraft heading and attitude angles are referenced to the platform. Synchro transmitters provide INS electrical outputs which represent these angles.

Two gyros and three accelerometers are mounted on the platform. Each gyro has two degrees of freedom. The gyro and accelerometer outputs are amplified and applied to the platform computer where they are summed and integrated. The aircraft velocities obtained by integration are used for computing the present aircraft position in terms of latitude and longitude. They are also summed with correction signals to develop gyro torquing signals to maintain the platform level.

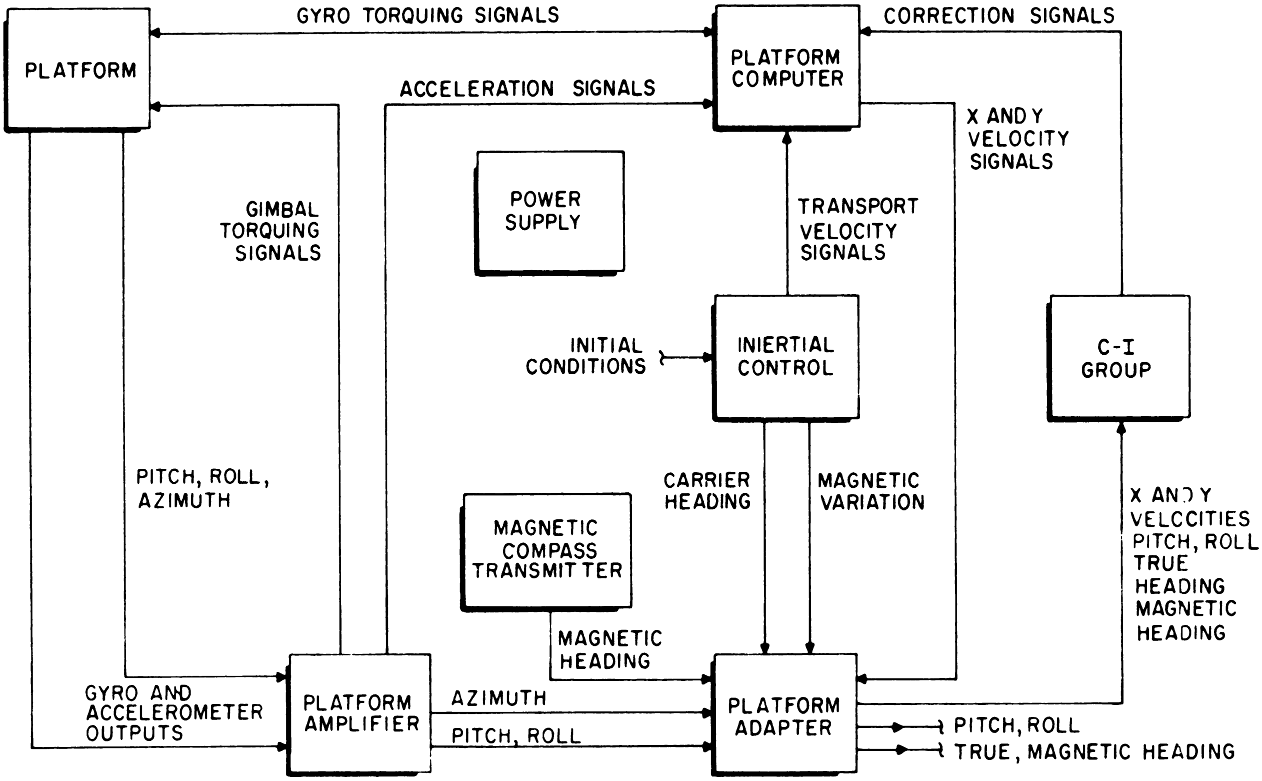

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Figure 17-34.–AN/ASN-36 INS, simplified system block diagram.

The gyros sense displacement of the platform's coordinate axes. Gyro outputs (precession signals) are applied to three servoloops whose outputs are converted into aircraft roll, pitch, and heading error signals, which are used to maintain the platform's initial orientation.

Synchro transmitters on the platform gimbals indicate aircraft attitude in the three axes, and their signals are processed and applied to other aircraft systems.

Operating Modes

The INS operates in several navigational modes. Inertial-Doppler is the normal mode; the others are provided for tactical reasons or to permit uninterrupted operation in the event of failure of other associated equipments.

INERTIAL-DOPPLER MODE.–In this mode, the INS outputs are relative velocities along the X and Y axes, aircraft pitch and roll, true heading, and magnetic heading. The relative velocities are used by the computer-indicator group in generating acceleration and gyro torquing correction signals for the INS. Doppler-derived signals (from Doppler velocity-sensing radar such as the AN/APN 153(V)) are also used in computing these correction signals, thereby improving the overall system accuracy.

INERTIAL MODE.–In this mode, the computer-indicator group presents position and correction data from the velocities furnished by the INS. Absence of Doppler-derived velocity information adversely affects system accuracy.

DOPPLER MODE.–In this mode, heading and attitude data are inertially derived in the same manner as in the inertial-Doppler mode. The computer-indicator group uses only Doppler velocities for computing present position. The correction signals are derived from Doppler data.

AIR DATA MODE.–In this mode, true heading output signals are provided by adding the flux valve and manually inserted magnetic variation angles. Attitude information may be derived from the INS. Only air data velocities are used for computing present positions.

C-I GROUP OFF MODE.–When the computer-indicator group is turned off, acceleration and gyro torquing correction are not supplied to the INS. Acceleration correction signals are generated within the platform computer by inertially derived quantities. Although there is some sacrifice in accuracy, the INS continues to function as an attitude reference, and supplies pitch, roll, magnetic heading, and true heading data to other aircraft systems. It also computes and displays (on its control unit) accurate latitude information.

ASSOCIATED EQUIPMENTS

In AEW aircraft such as the E-2A, the AN/ASN-36 inertial navigation system comprises a portion of the overall Doppler-inertial navigation system used to provide accurate velocity, attitude, and heading data. These data are then used in the digital data processing system, the AN/ASA-27 control-indicator group, for computing the aircraft's present position.

The INS is used in conjunction with a Doppler velocity-sensing radar such as the AN/APN-153(V). When used in combination, the overall system accuracy is greatly improved by making use of the outstanding features of each system to compensate for the weaknesses of the other.

In most INS systems, the aircraft compass system and pitot pressure system are used (or at least made available for use) in the event of nonoperation of portions of the INS.

OTHER INS SYSTEMS

The AN/ASN-31

Basically, the theories of operation of the AN/ASN-31 and the AN/ASN-36 systems are similar, although aircraft missions are different, and some differences do exist in details of operation. The AN/ASN-31 INS is used in model A-6A attack weapon system to provide velocity, attitude, and heading information to the AN/ASQ-61 ballistics computer set, which computes present aircraft position. Several modules are interchangeable between the two equipments.

The AN/ASN-31 has provisions for switching from a navigation coordinate system referenced to true north to a system referenced to grid north when the aircraft is flying inside the polar region (inside 70° latitude north or south). Grid north is a line parallel to the line of longitude which was used for initial INS alinement. The AN/ASN-36 does not possess this feature.

The LN-12

This INS is a small, compact, lightweight system used in the F-4B high speed intercept fighter. It is used in conjunction with the AN/ASN-46 navigation computer set, which computes the great circle (shortest) route to the target or base using spherical trigonometry.

CHAPTER 18

AIRBORNE RADAR

The term radar is used to describe electronic systems which are used to locate airborne or surface targets. A review of the introduction to radar in Basic Electronics, NavPers 10087-B, reveals that the word RADAR is an abbreviation for RAdio Detection and Ranging. In addition to indicating the presence of targets, radar may also be used to determine bearing, distance, elevation, speed, relative size, and identification. The accuracy of each use of radar is determined by several characteristics.

CHARACTERISTICS OF RADAR

RANGE

Radar measurement of range or distance is possible because of the fact that radiated RF energy travels through space in a straight line at a constant velocity. The straight path and constant speed are changed slightly when the RF waves enter the atmosphere and will vary with atmospheric and weather conditions. (This is discussed later in this chapter.)

Velocity

RF energy travels at the speed of light, about 186,000 statute miles (162,000 nautical miles) per second. This is 300,000,000 meters per second in the metric system. Radar timing is usually expressed in microseconds, and the velocity of radar waves is often given as 328 yards of 984 feet per microsecond.

One nautical mile is equal to approximately 6,080 feet. This means that it takes RF energy approximately 6.18 microseconds to travel 1 mile.

Range Measurement

The pulse type radar set determines range by measuring the elapsed time during which the emitted pulse travels to the target and returns. Since two-way travel is involved, a total time of 12.36 microseconds per nautical mile will elapse between the start of the pulse from the antenna and its return from a target. The range in nautical miles of any object can be found by measuring the time elapsing during a round trip of the radar pulse (in microseconds) and dividing this quantity by 12.36. In equation form, this is:

$$\text{Range} = \frac{\text{elapsed time}}{12.36}$$

MINIMUM RANGE.–The minimum range capability of a radar is determined by the time of the transmitter pulse, or pulse width (PW), plus the recovery time of the duplexer and the receiver. (For purposes of this explanation, recovery time may be considered as the time required for the receiver to become operative after the transmitter has fired.)

The minimum range in yards, at which a target can be detected, is equal to the PW plus the recovery time, divided by 2 and multiplied by 328 yards (328 yd/μsec.).
Stated in formula:

$$\text{Minimum range} = \frac{\text{PW + recovery time}}{2} \times 328 \text{ yd}$$

$$= (\text{PW + recovery time}) \times 164 \text{ yd}$$

Targets closer than this range are not seen because the receiver is inoperative for the period of time necessary for a signal to travel this distance.

An increase in recovery time (bad TR tube in the duplexer) not only increases the minimum range, but also decreases the receiver sensitivity.

MAXIMUM RANGE.–The higher the frequency of a radar wave, the greater the attenuation (decrease in signal strength) due to weather effect. Gases and water vapor that make up the atmosphere absorb energy from the radiated pulse. Frequencies below 3,000 MHz are not appreciably attenuated under normal conditions, while frequencies above 10,000 MHz are highly attenuated. Attenuation of the transmitted pulse results in a decrease in the ability of the radar to produce usable echoes at long ranges. A usable echo may be defined roughly as the smallest signal which a receiver-indicator system is able to detect, amplify, and present so that the observer can visually distinguish it from the noise signals on the CRT.

At lower frequencies, higher transmitter power can be developed more easily. Also, there is greater refraction and diffraction (bending of the waves). Lower radar frequencies are therefore superior for extremely long-range search radar. The effect of atmospheric conditions on radar signals is discussed in more detail later in this chapter.

The maximum range of any radar depends upon transmitted power, pulse repetition frequency, and receiver sensitivity. The peak power of the transmitted pulse determines the maximum range that the pulse can travel to a target and return in usable echo strength. Sufficient time must be allowed between transmitted pulses for an echo to return from a target located at the maximum range (established by design) of the system.

The maximum range is sometimes extended and vertical coverage reduced by the trapping of the radar beam in a DUCT. A duct is created by abnormal weather conditions; further coverage on ducts is given later in this chapter.

AZIMUTH

The azimuth (bearing) of a target is its clockwise angular displacement in the horizontal plane with respect to true north as distinguished from magnetic north. This angle may be measured with respect to the heading of an aircraft containing the radar set; in this case, it is called relative bearing. The angle may be measured from true north, giving true bearing, if the installation contains azimuth stabilization equipment. The angle is measured by utilizing the directional characteristics of an unidirectional antenna, and determining the position of the antenna when the strongest echo is received from the target.

Radar antennas are constructed of radiating elements and reflectors, and some types use a director element to produce a narrow beam of energy in one direction. The pattern produced in this manner permits the beaming of maximum energy in a desired direction. The transmitting pattern of an antenna system is also its receiving pattern. An antenna can therefore be used to transmit energy, to receive echoes (reflected energy), or both.

RESOLUTION

The range resolution of a radar is the minimum resolvable separation in range of two targets of the same bearing. Range resolution is a function of the width of the transmitted pulse, the type and size of the targets, and the characteristics of the receiver and indicator. With a well-designed radar, sharply defined targets on the same bearing should be resolved if their ranges differ by the distance the pulse travels in one-half of the time of the pulse width (164 yards per microsecond of PW). If a radar set has a pulse width of 5 microseconds, the targets would have to be separated by more than 820 yards before they would appear as two pips on the scope.

The azimuth resolution is the ability to separate targets at the same range but on different bearings, and is a function of the antenna beam width and the range of the targets. Antenna beam width may be defined as the angular distance between the half-power points of an antenna's radiation pattern. (Half-power points are those points at which the transmitted power is one-half the maximum value of energy that is radiated along the lobe center.) Two targets at the same range, in order to be resolved as being two targets instead of one, must be separated by at least one beam width.

Strong multiple targets appearing as one target can often be resolved in azimuth and bearing by reducing the gain of the receiver until only the strongest portions of the echoes appear on the CRT.

ACCURACY

The accuracy of a radar is a measure of its ability to determine the correct range and bearing of a target. The degree of accuracy in azimuth is determined by the effective beam width and is improved as the beam width is narrowed. On a PPI scope the echo begins to appear when energy in the edge of the beam first strikes the target. The echo is strongest as the axis of the beam crosses the target, but the echo continues to appear on the scope as long as any part of the beam strikes the target. The target appears wider on the PPI than it actually is, and the relative accuracy of the presentation depends in a large measure on the width of the radar beam and range to the target.

The true range of a target is the actual distance between the target and the radar set (fig. 18-1). In airborne radar, the true range is often called SLANT RANGE. The term slant range is used to indicate that the range measurement includes the effect of difference in altitude.

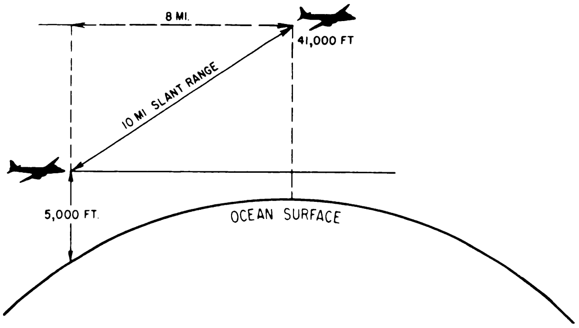

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Figure 18-1.—Slant range versus horizontal range.

The horizontal range of a target is a straight line distance (fig. 18-1) along an imaginary arc parallel to the earth's surface. This concept is important to the radar observer because an airborne target, or the observer's aircraft, need only to travel the distance represented by its horizontal range to reach a position directly over its target. For example, an aircraft at a slant or true range of 10 miles, and at an altitude of 36,000 feet above the radar observer's aircraft, possesses a horizontal range of only 8 miles.

The timing sequence of a radar range indicating device starts at the same instant that the transmitter starts operation. Therefore, with airborne surface-search radar, the first targets seen are those directly beneath the aircraft. However, on the PPI scope, there is a hole in the middle of the picture (fig. 18-2), with a minimum radius corresponding to the altitude of the aircraft. In some systems the radius of the altitude ring will vary as the lower limit of the vertical radiation pattern is increased by raising the tilt of the radar antenna. Objects which are actually directly beneath the aircraft appear on the scope at a distance equal to the distance between the aircraft and ground. For greater accuracy of surface ranges, the relationship between the range of the target and the range of the altitude ring must be considered.

FACTORS AFFECTING RADAR

There are many factors, or elements (including atmospheric conditions), that affect radar performance. One of the principal factors is maintenance. The ability to keep the equipment operating at peak efficiency will influence the overall capabilities and limitations of the radar.

Another important factor is the radar operator's knowledge of the equipment. He must know the maximum and minimum ranges at which he can expect to pick up various targets, range and bearing accuracy of the gear, and range and bearing resolution. If the radar is a height finder, the operator must know the altitude determination accuracy and the altitude resolution. Information on these factors is contained in the Operation and Service Instruction Manual for each radar.

Peak Power

The peak power of a radar is its useful power. Range capabilities of the radar will increase with an increase in peak power. Doubling the peak power (a 3-db gain) will increase the range capabilities by about 25 percent.

Pulse Width

The longer the pulse width, the greater the range capabilities of the radar. This is due to the greater amount of RF energy sent out in each pulse. In addition, consider the fact that narrow bandpass receivers may be used, thus reducing noise level. An increase in pulse width, however, reduces the range resolution capabilities of the system.

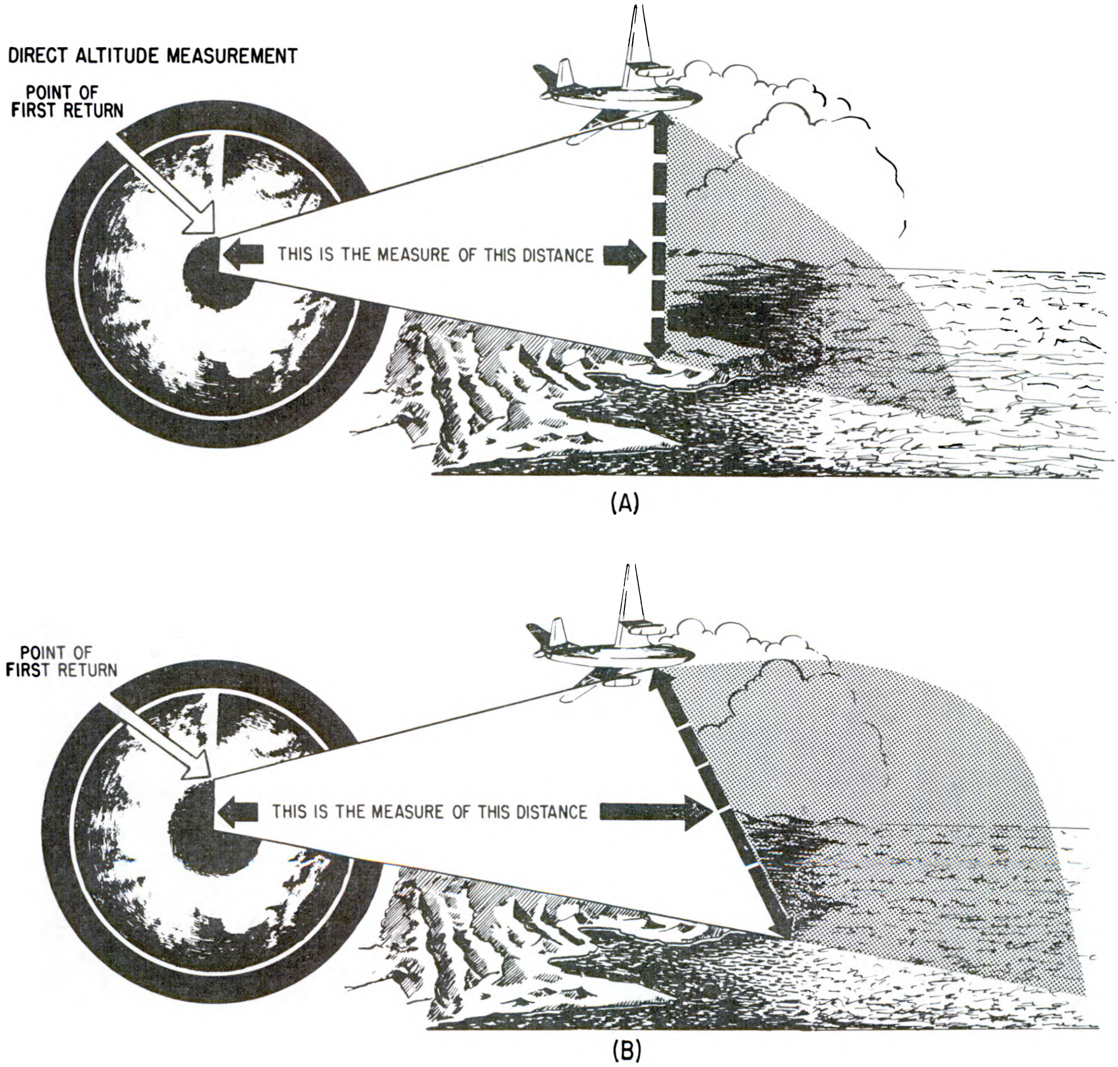
DIRECT ALTITUDE MEASUREMENT
POINT OF FIRST RETURN
THIS IS THE MEASURE OF THIS DISTANCE
(A)
POINT OF FIRST RETURN
THIS IS THE MEASURE OF THIS DISTANCE
(B)

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Figure 18-2.–Effect of altitude on radar. (A) Radar tilted down; (B) radar with zero tilt.

Beam Width

The beam width is specified in degrees between the half-power points in the radiation pattern.

The effective beam width of a radar is not a constant quantity because it is affected by the receiver gain (sensitivity) and the size and range of the target.

The narrower the beam width, the greater the concentration of energy. The more concentrated the beam, the greater the range capabilities for a given amount of transmitted power.

Receiver Sensitivity

The sensitivity of a receiver is a measure of the ability of the receiver to amplify and make usable a very weak signal. The more sensitive the receiver, the greater the detection range of the radar. Sensitive receivers are easier to jam, however, and interference will show on the scope more easily.

Indicators

The choice of the type of scope used to display weak pips will add to the capabilities of the radar. The deflection-modulated A-scope is more sensitive to weak echoes than the intensity-modulated PPI. In some airborne installations that carry an oscilloscope for maintenance purposes, a weak target can be seen on the A-scope before it can be detected on the PPI.

Antenna Rotation

The more slowly the antenna rotates, the greater the detection range of the radar. Thus, an antenna which is not rotating would afford the greatest range in the direction it is pointing, within the limits of the radar. For tactical reasons, it is best not to stop the antenna from rotating and point the antenna beam at the target, except momentarily, and then only to gain information on composition of a target.

Atmospheric Conditions

The paths followed by microwave and VHF signals, whether direct or reflected, usually are slightly curved. The signals travel through the atmosphere at speeds that depend on temperature, atmospheric pressure, and the amount of water vapor present in the atmosphere. Generally, the higher the temperature the faster the signal; the lower the atmospheric pressure, the faster the signal; and the less the amount of water vapor present, the faster the signal. The net result of these influences is that the signal speed changes with altitude and, under normal atmospheric conditions, the variation is a small and uniform increase in the speed of the signal with increasing altitude. This causes all paths to curve slightly downward, as shown in figure 18-3, extending the radar horizon beyond a tangent to the earth. (See fig. 18-4.) The amount of the extension of the radar horizon varies with weather conditions. Under normal conditions, the radar horizon is extended 1.25 times the optical line of sight.

To understand the reason for this curving downward, imagine a surface called a wave front such as the one represented by line AB (fig. 18-3), where A is higher in altitude than B. A wave front is a surface, not necessarily flat, chosen in such a way that the phase of the signal is the same at all points on the surface. The signal always travels in a direction perpendicular to the wave front. Now, as wave front AB moves with the signal, it reaches position A'B' after a short time interval. The speed at A and A' is faster than the speed at B and B', since A and A' are at a greater altitude. Therefore, in a given time, the upper part of the wave front moves farther than the lower part, and the wave front tips slightly forward as it moves along. Since the path followed by the signal is always

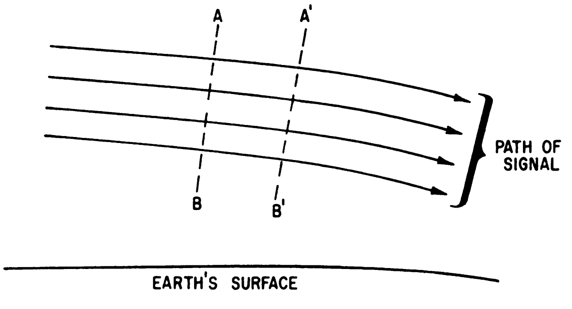

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Figure 18-3.—Microwave path.

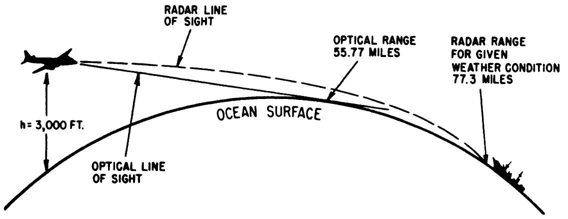

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Figure 18-4.–Extension of radar horizon.

perpendicular to the wave front, it curves slightly downward as the wave front tips.

The bending of radio or radar waves due to a change in the density of the medium through which they are passing is termed refraction. The measure of the bending that occurs is indicated by the difference in index of refraction from one substance to another. The density of the atmosphere changes at a gradual and continuous rate; therefore, the index of refraction changes gradually with increased height.

The temperature and the moisture content of the atmosphere normally decrease with height above the surface of the earth. Under certain conditions, the temperature may first increase with height and then begin to decrease. Such a situation is called temperature inversion. More important, the moisture content may decrease more rapidly with height just above the sea. This effect is called moisture lapse.

Either temperature inversion or moisture lapse, alone or in combination, may produce a great change in the index of refraction of the lowest few hundred feet of the atmosphere, resulting in greater bending of the radar waves. This may greatly extend or reduce the radar horizon, depending on the direction in which the radar waves are bent. The height of the radar antenna with respect to the DUCT formed by this strange occurrence is of much importance.

Although duct conditions can happen any place in the world, the climate and weather in some areas make their occurrence more likely. In some parts of the world, particularly those having a monsoonal climate, variation in the degree of duct formation is mainly seasonal, and great changes from day to day may not take place. In other parts of the world, especially those in which low barometric pressure areas recur often, the extent of nonstandard propagation conditions varies considerably from day to day, even during the season when they are most common.

Sometimes, for various reasons in different areas, some upper level air becomes heated and often partially dried out. This effect is associated with clear weather rather than with storms. The temperature inversion and a layer of very dry air, which spreads out horizontally, create conditions favorable to the formation of a sky duct. The top of a duct can often be recognized by a thin layer of haze. The haze is a result of the moisture in the warm air condensing as the air starts to get colder.

The height and width of ducts can be predicted by the meteorological office. This is done by plotting temperature variations versus height. Figure 18-5 shows a standard variation chart compared with charts of nonstandard conditions.

TYPES OF AIRBORNE RADAR

The fundamental principles of all radar are similar; however, there are two basic types of radar systems–pulse and CW (continuous wave). FM radar is a type of CW radar. The Doppler principle can be used in both CW and pulse radars. The distinction between CW and pulse radar becomes less clear in systems where a combination of pulse and CW techniques is used. In general, a radar system is considered a pulse system when the RF energy is emitted less than 10 percent of the time. Most pulse radars emit energy less than 0.1 percent of the time. When the radar emits energy more than 10 percent of the time, it is classified as a CW radar system.

Most of the emphasis in radar development has been on pulse radar systems, primarily because of the rate at which information is collected, as compared to CW radar. However, there are specific applications in which CW radar performs more efficiently than pulse radar; for example, working to zero range and reduction of ground clutter.

Radar is a powerful aid to the aircraft, and the aircraft is an aid to the radar. The aircraft supplies an elevated platform to the radar, thereby extending the effective range at which objects can be detected. The application of radar to airborne operations has been most successful

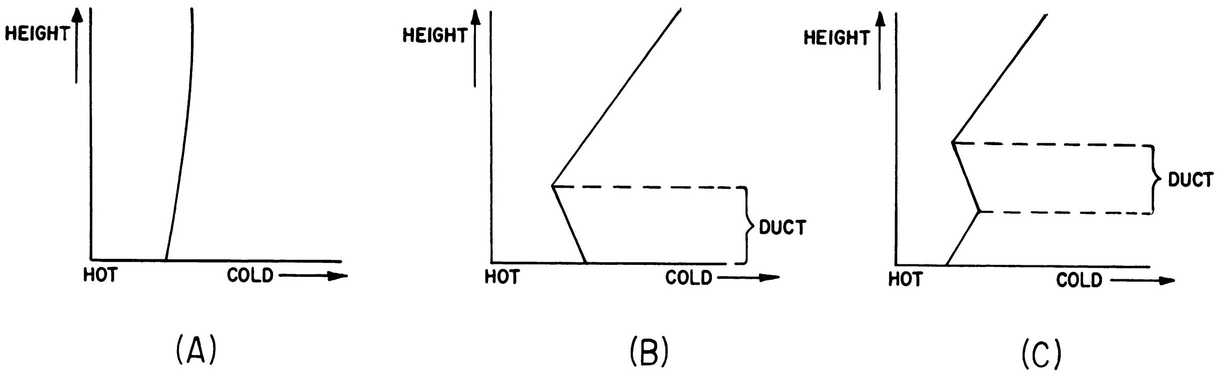

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Figure 18-5.—Height versus temperature. (A) Standard variation; (B) surface duct; (C) sky duct.

and airborne radar is an indispensable part of the Navy's fighting team. In naval aircraft, radar has many different uses, each requiring a different application of the fundamental principles.

SEARCH

Search radar, the basic type used in many radar-equipped aircraft, shows the range and azimuth of targets such as ships, islands, coastlines, and other aircraft within the reach of its beam. Search radar is an effective aid to air navigation since it exhibits land masses and storm clouds on the radar screen. In larger aircraft the IFF interrogation antenna is mounted on the search radar antenna in order to obtain IFF target bearing and range, which identifies ships and aircraft as friendly or hostile by means of coded replies.

Airborne search radar is generally classified as medium range and operates in either S-band or X-band. Figure 18-6 indicates the relative positions of the S-band and the X-band. The pulse width utilized by the radar is variable, depending on the range selected: on shorter ranges a narrow pulse width (0.5μsec.) is used; longer ranges may use a pulse width up to 5μ sec. The narrow pulse width permits a short

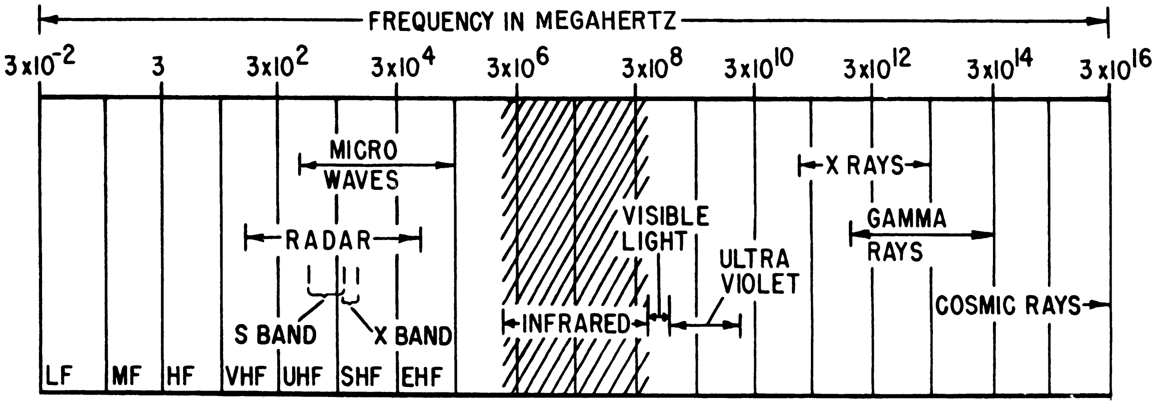

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Figure 18-6.—Electromagnetic energy spectrum.

minimum range, a high degree of range resolution, and greater range accuracy. The wide pulse width is used to aid in detecting small targets at greater distances.

The pulse repetition frequency (PRF) of the radar also usually varies with the ranges used—a high PRF is used on the shorter ranges for better target illumination, and a low PRF is used for obtaining greater maximum ranges.

HEIGHT FINDING

Height-finding radar is used to determine the altitude of a target by placing a narrow vertical beam on the target and measuring the position angle. The position angle is combined with the slant range to compute the altitude of the target above the horizontal. In airborne use the computed altitude of the target may be either the height above your aircraft or the height above ground. For computation of the target's altitude above ground, the altitude of your aircraft must be set in.

Another type of height-finding radar is the absolute altimeter. The absolute altimeter (radar altimeter) measures the distance from the aircraft to the ground or objects below. This is done by transmitting RF energy down, and receiving the reflected energy at the aircraft. In FM equipment the altitude is determined by the frequency difference between the reflected signal and the transmitter signal. In pulse equipment the altitude is determined by measuring the time required for the transmitted pulse to hit the ground and return. The indicating instrument will indicate the true altitude of the aircraft, which is its height above water, mountains, buildings, or other objects on the surface of the earth.

FIRE CONTROL

There are three basic types of fire control systems found in naval aviation. They are the day intercept system (visual), the all-weather intercept system, and the missile control system. (NOTE: For purpose of clarity, missile control systems are covered separately.) The day intercept system currently uses either of two types of automatic range only (ARO) radar.

One type uses a fixed antenna and furnishes range information to a computer group. The pilot, with the aid of the optical sight, aims his aircraft at the target. The radar then locks on the target and furnishes range information to the computer. Range may also be indicated on a meter or range indicator in the cockpit.

Another type of ARO radar has an antenna that scans in azimuth and indicates the heading and range to a target on a CRT. It also displays an artificial-horizon bar to aid the pilot in flying the aircraft. The search mode of this type radar provides range and direction information for use in maneuvering the aircraft to within visual attack range. Once visual contact is made, the antenna is locked in the dead ahead position and the attack is completed, using the optical system with the radar supplying range and range rate information to the computer.

The all-weather firecontrol system uses radar rather than optical means to search out a target. Once a target is found and selected, the radar tracks the target in range, elevation, and azimuth, and presents steering information on the flight indicator screen (CRT). This equipment may also provide a surface-search mode of operation. In the all-weather mode of operation, the computed lead angles are presented on the CRT. In the visual mode, the radar antenna is pointed dead ahead and the set functions as an ARO radar.

Missile Control

The radar used in the missile control system is essentially the same as that used in the all-weather system with the addition of a CW radar group. The CW radar is used to illuminate the target and usually shares the same antenna with the pulse radar. Since modern missiles utilizing CW radar carry their own computing circuits and determine their own flightpath, the CW radar can be a relatively simple system. In use, the target is detected and tracked with the pulse radar, while the CW radar illuminates the target with CW energy. The missile homes on this reflected CW energy.

NAVIGATION

Doppler navigational radar automatically and continuously computes and displays groundspeed and drift angle of an aircraft in flight without the aid of ground stations, wind estimates, or true airspeed data. This is done by utilizing auxiliary inputs from an altitude rate sensor and from the aircraft's vertical reference system. The radar section does not sense range and bearing (direction) as ordinary search radar does. Instead, it is speed-conscious and drift-conscious. It employs continuous carrier wave transmission energy and determines the forward and lateral velocity components of the aircraft by utilizing the principle known as Doppler effect.

The Doppler effect, or frequency change of a signal, can be explained in terms of an approaching and receding audio sound emitter. As shown in figure 18-7 (A), the sound emitter is on a moving ambulance and the receiver is the ear of a stationary listener. Assume that the frequency of the siren is 1,000 Hz.

Notice the spacing between the waves from the stationary emitter, as illustrated in figure 18-7 (B). If the emitter and listener were standing still, then 1,000 waves of sound energy would reach the listener in one second.

In figure 18-7 (C), the emitter is moving toward the listener (closing). The emitter moves a little closer to the listener between successive waves of energy, so each wave reaches the listener sooner than it would if the emitter were stationary. This means that the listener hears more than 1,000 waves of energy in one second, and consequently the sound is higher in pitch.

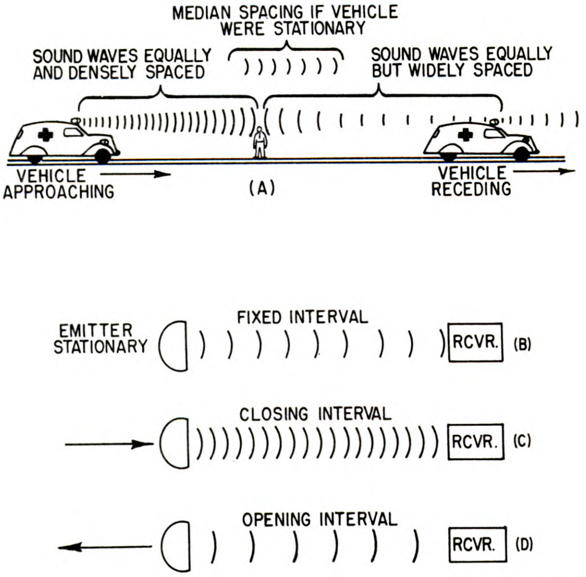

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Figure 18-7.—Doppler effect with sound waves.

The reverse is true in figure 18-7 (D). The emitter is moving away (opening), so the interval between successive waves is greater. Since the listener hears less than 1,000 waves in one second, the frequency of the emitter seems lower than it actually is.

Doppler radar employs the frequency change phenomenon just described, except in the RF frefrequency range.

The radar emits CW energy at one frequency, and these waves of energy strike the target and are reflected. Energy waves returning from the target are spaced differently than the waves striking the target. A closing target moves a little closer to the radar between successive waves, and reflects the waves sooner than if it were stationary. The closer-spaced waves mean that the frequency has increased slightly.

If the target moves toward the radar or if the radar moves toward the target faster, the waves of energy will be even closer together, causing a greater frequency change. The faster the closing speed, the higher will be the frequency of the returning waves.

The receiver of the Doppler radar system has two signal inputs—one from the transmitter, and one from the receiver antenna. The input signal from the transmitter is at all times the same frequency as the signal being radiated; the receiver antenna signal frequency will vary with the relative speed of the target and the radar. The two frequencies are compared in the receiver, and the difference frequency is a direct indication of the closing or opening speed of the target.

The Doppler effect is present any time there is relative motion (opening or closing distance) between the radar and the target. Therefore, the radar could be moving toward a stationary target and the effect would be the same as if a target moved toward a stationary radar.

One type of airborne Doppler navigation equipment is an all-weather, self-contained system. It radiates two narrow, fixed beams of CW energy downward, outward, and rearward (thus the ground becomes an opening target) from the aircraft's longitudinal axis. The ground-returned energy is intercepted by the receiver and compared with the outgoing transmitter energy. The difference (due to the Doppler effect) is used to develop velocity component information for use in the computing section. The velocity component, with the aid of roll-angle, pitch-angle, altitude, and altitude-rate data furnished from auxiliary equipment, derives the ground-speed and drift angle in the computing section.

The groundspeed and drift angle information is continuously displayed on an indicating dial. It is also made available as a continuous synchro output signal for tie-in with other navigational equipment—position computers, bomb directors, and integrated flight director systems.

RADAR CIRCUIT THEORY

Radar equipments vary considerably in detail, depending on the amount of information and the accuracy of the data which they are required to supply. However, all radar systems using pulse modulation work on essentially the same principles, and their basic operations depend on the same kinds of major components. A basic radar system is shown in simplified block diagram form in figure 18-8.

SYNCHRONIZER

The synchronizer is the timing unit which is the heart of the entire system. It produces trigger pulses which control and coordinate the circuits of the system so that each operates at the correct time. In most systems it governs the number of pulses the transmitter produces in each second. It coordinates the sweep voltage (or current) to the indicator tube with the firing of the transmitter, and contains provisions for delaying the beginning of the sweep to give special types of display (such as open center and target discrimination operation). The synchronizer contains the circuits which generate the range marker voltages and the trigger pulses which unblank the indicator tube when the trace starts to appear on the screen. Pulses supplied by the synchronizer are also used to indirectly control the associated equipment used with the search system.

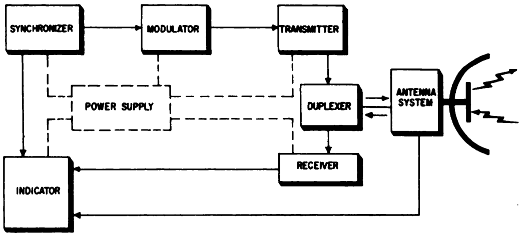

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Figure 18-8.—Block diagram of basic airborne radar system.

In some equipments the master trigger is synchronized with the aircraft's 400 Hz a-c power. The 115-volt a-c power input to the synchronizer (fig. 18-9) is connected to peaking choke L1. The output from the choke is a positive and a negative pulse at line frequency or 380 Hz to 420 Hz. The choke output is fed to a biased cathode follower, V1A. This tube is biased below cutoff; therefore, only the positive pulse is applied to the input of blocking oscillator V1B. The output (PRF) from the blocking oscillator is the same as the powerline frequency.

Eight output triggers are developed from the master trigger. Two of the output triggers are coincident with the master trigger. The other six triggers are delayed in delay lines. Taps are provided on the synchronizer delay lines for the following delays: one fixed at 15μsec., another fixed at 24 μ sec., two fixed at 30μ sec., and two jointly variable from 15 to 32μ sec. The variable delay is provided by switches and a relay. The relay is controlled by a remote switch at the operator's station and provides the modulator with a choice of two trigger delays for sonobuoy or search operation. This variable delay is adjustable by two coarse and two fine controls on the front of the synchronizer. Cathode followers provided low-impedance outputs for the triggers. The block diagram in figure 18-10 illustrates the sequence and use of the output triggers.

Some radar synchronizers utilize a multivibrator for the master oscillator. They normally contain switching provisions for changing the output frequency (PRF).

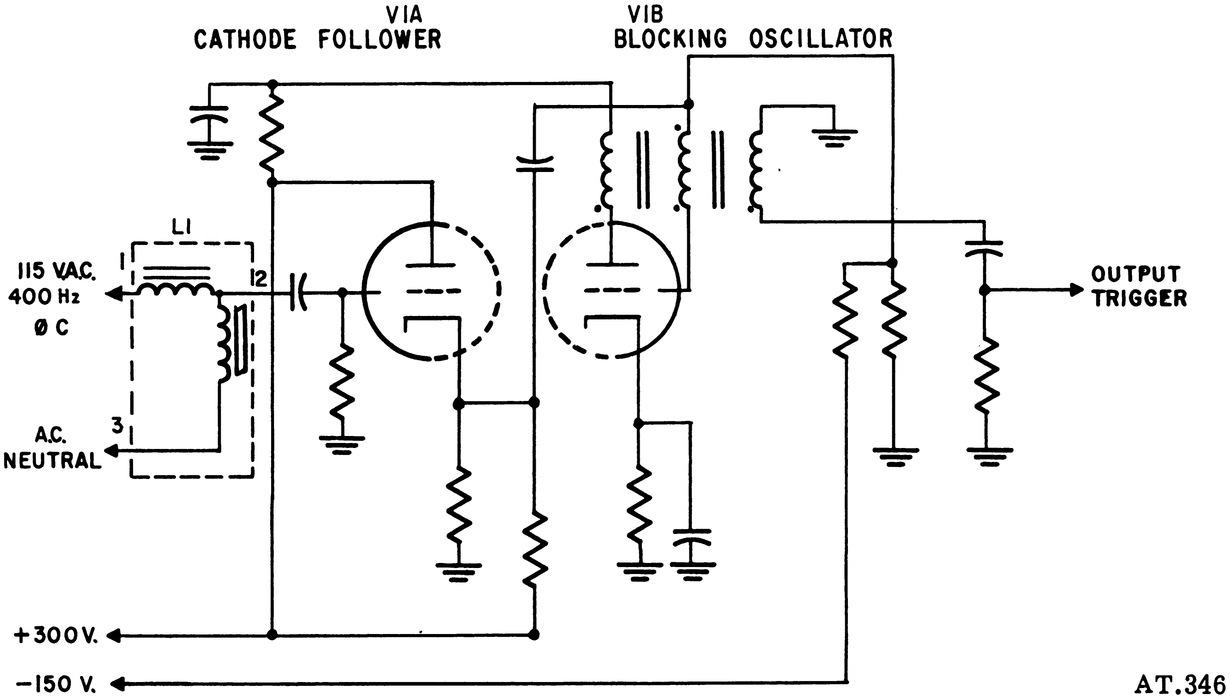


Figure 18-9.–Master trigger circuit.

MODULATOR

The modulator controls the operation of the transmitter by applying high-voltage pulses of rectangular shape. The pulses are usually supplied by charging a section of artificial transmission line in the modulator to a high potential during the interval between pulses. The modulator action begins when a trigger pulse from the synchronizer is applied to an electronic switch tube in the modulator unit. The switch tube terminates the artificial line and causes it to discharge a rectangular pulse through the transmitter tube. The length of time during which energy is transmitted is called the pulse width. In airborne applications, the modulator unit is usually enclosed in a container and operated under a constant pressure to prevent high-voltage arcing.

Figure 18-11 illustrates a block diagram of a modulator and high-voltage power supply.

Three-phase, 400 Hz power is supplied to the modulator through a variable power transformer (autotransformer or Variac). This transformer controls the amplitude of the high-voltage pulse to the magnetron by controlling the input voltage to the high-voltage rectifier.

The output from the high-voltage rectifier is applied through charging choke L1 to the series-resonant pulse forming network (PFN), Z1. Charging diodes hold the peak voltage on the PFN after the charge cycle is over.

To discharge the PFN, the thyratron switch tube is ionized by a trigger from the synchronizer. When the thyratron is ionized, it acts as a shorting switch on the input terminal of the PFN. The PFN is discharged through the primary of a transformer in the receiver-transmitter.

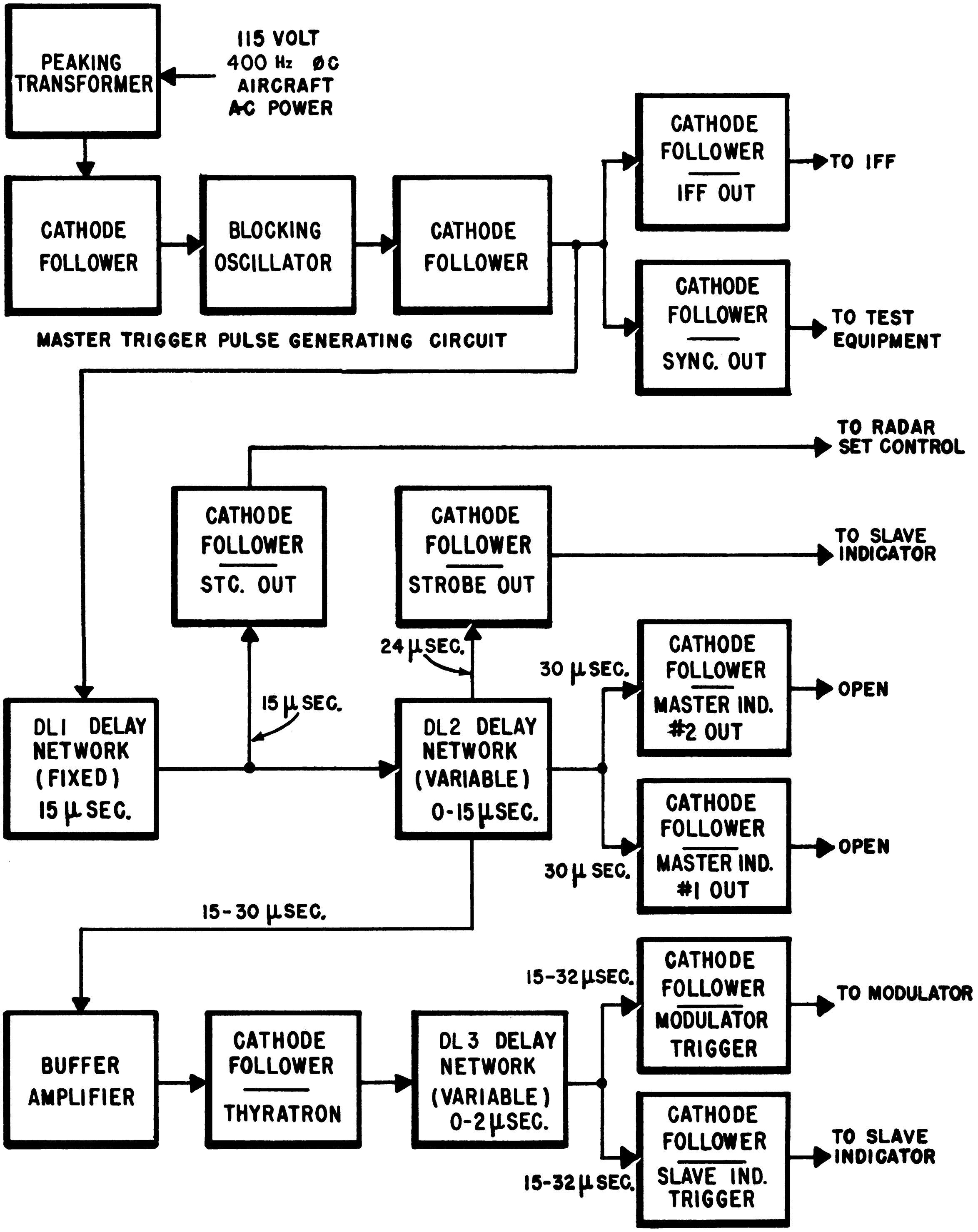
Inverse diode CR6 shunts the pulse forming network to damp out switching oscillations, and to shunt to ground any negative voltage appearing on the input terminal of the PFN caused by the magnetron or by waveguide arcing.

Blocking oscillator V2 increases the amplitude and shape of the positive input trigger from the electrical synchronizer for reliable triggering of the thyratron switch tube.

Cathode follower V3 isolates the blocking oscillator from the thyratron grid, which prevents oscillations that could cause multiple triggering.

TRANSMITTER

The transmitter consists principally of a magnetron which oscillates at extremely high frequency throughout the interval of the pulse applied by the modulator. The magnetron produces the electromagnetic energy which is



AT.347

Figure 18-10.—Block diagram, synchronizer.

radiated from the antenna into space. Airborne radar sets employ microwaves, a typical value of wavelength being about 3 centimeters. The output of the magnetron is conducted to the antenna through waveguide transmission lines consisting of hollow metal tubing.

The high-voltage pulse section, which includes the magnetron, receives the high-voltage pulse from the modulator; the voltage is stepped up by pulse transformer T4. (See fig. 18-12.)

Pulse transformer T4 has two secondary windings of similar electrical characteristics, each connected to a filament lead of the magnetron. These two windings maintain an equal and in-phase voltage on each side of the filament when T4 receives the high-voltage pulse from the modulator. The electrical action of these windings, with associated capacitors, prevents the high-voltage pulses from appearing across the filament of the magnetron or the

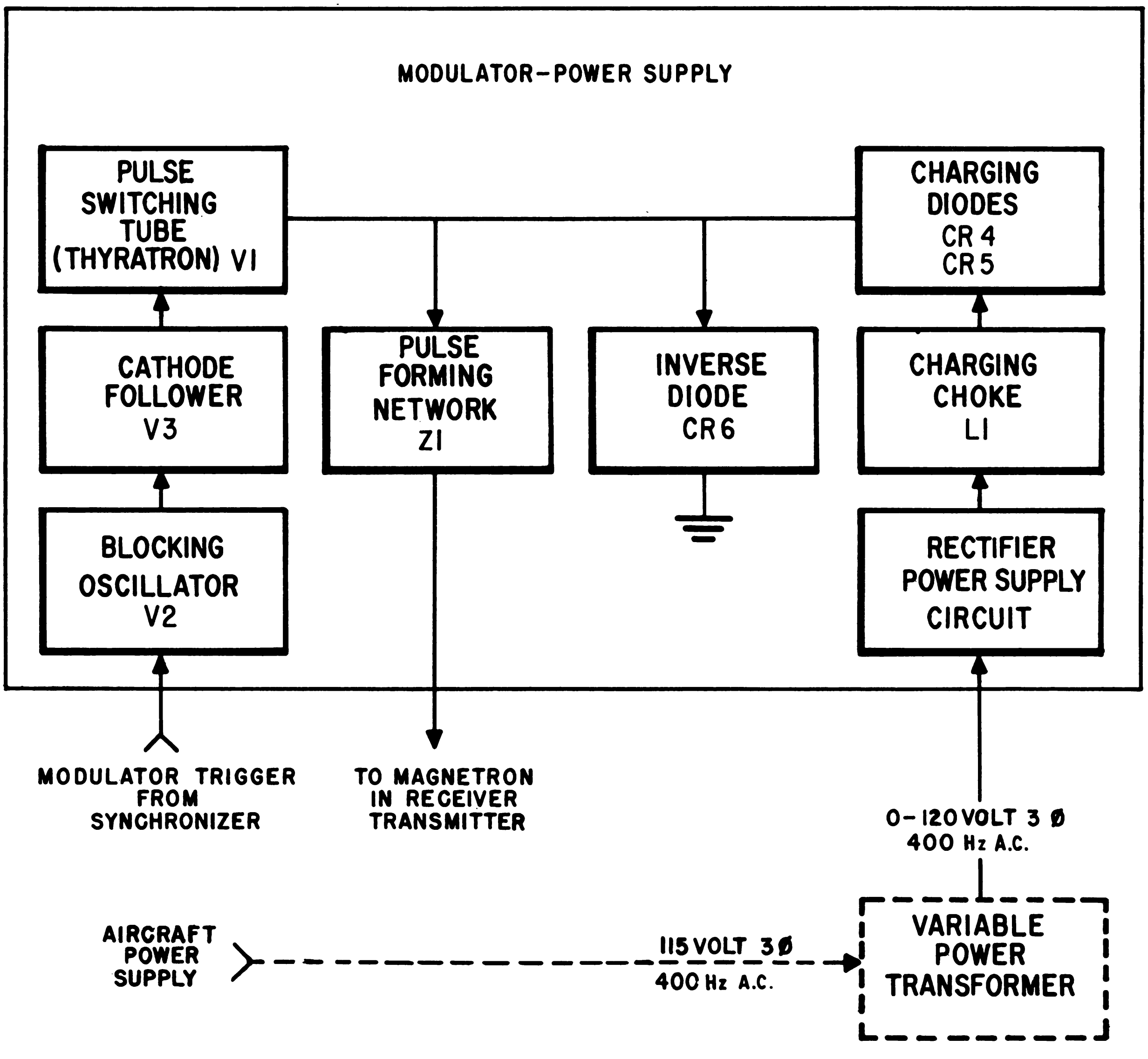

MODULATOR-POWER SUPPLY
PULSE SWITCHING TUBE (THYRATRON) V1
CATHODE FOLLOWER V3
BLOCKING OSCILLATOR V2
PULSE FORMING NETWORK Z1
INVERSE DIODE CR6
CHARGING DIODES CR 4 CR 5
CHARGING CHOKE L1
RECTIFIER POWER SUPPLY CIRCUIT
MODULATOR TRIGGER FROM SYNCHRONIZER
TO MAGNETRON IN RECEIVER TRANSMITTER
0-120 VOLT 3 Ø 400 Hz A.C.
AIRCRAFT POWER SUPPLY
115 VOLT 3Ø 400 Hz A.C.
VARIABLE POWER TRANSFORMER

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Figure 18-11.—Block diagram of modulator function.

secondary of the magnetron filament transformer.

Each pulse drives the cathode of the magnetron negative. This causes the magnetron to oscillate for the duration of the pulse. These high-power pulses of RF energy are coupled into the waveguide section duplexer.

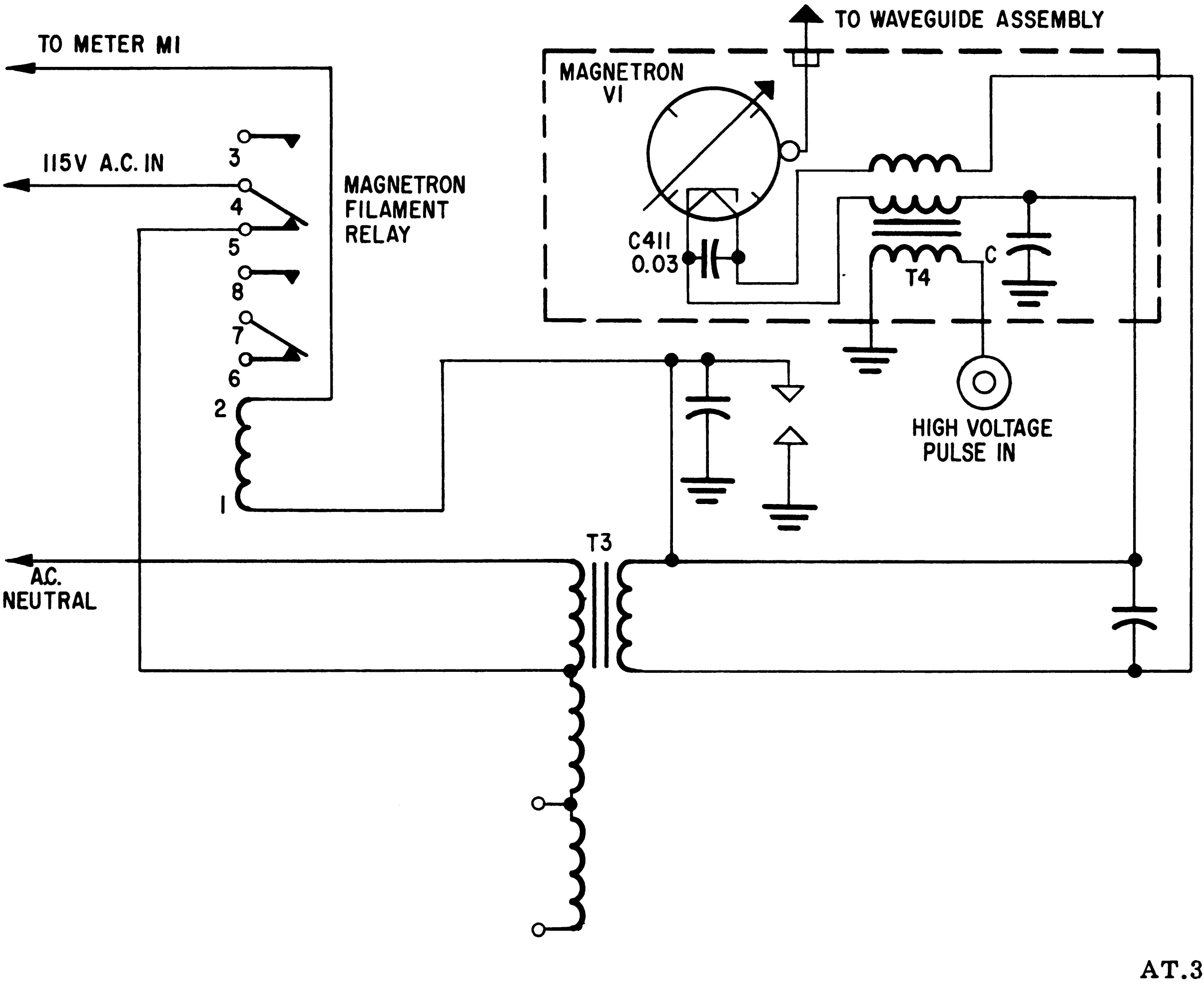
WAVEGUIDE AND DUPLEXER

The waveguide assembly (fig. 18-13 couples RF from the magnetron to the antenna for transmitting and the received echo from the antenna to the receiver.

All coupling between sections is accomplished by choke coupling. Choke coupling is accomplished by standard fittings designed to present low-impedance points at the junctions of the inside walls of the waveguide.

The transmitter and the receiver are effectively isolated from each other during each function by means of a load isolater and the duplexer assembly. The RF output from the magnetron is coupled to the duplexer through a section of waveguide that contains a ferrite load isolator.

The load isolator, W2, is a section of waveguide containing a ferrite element and a

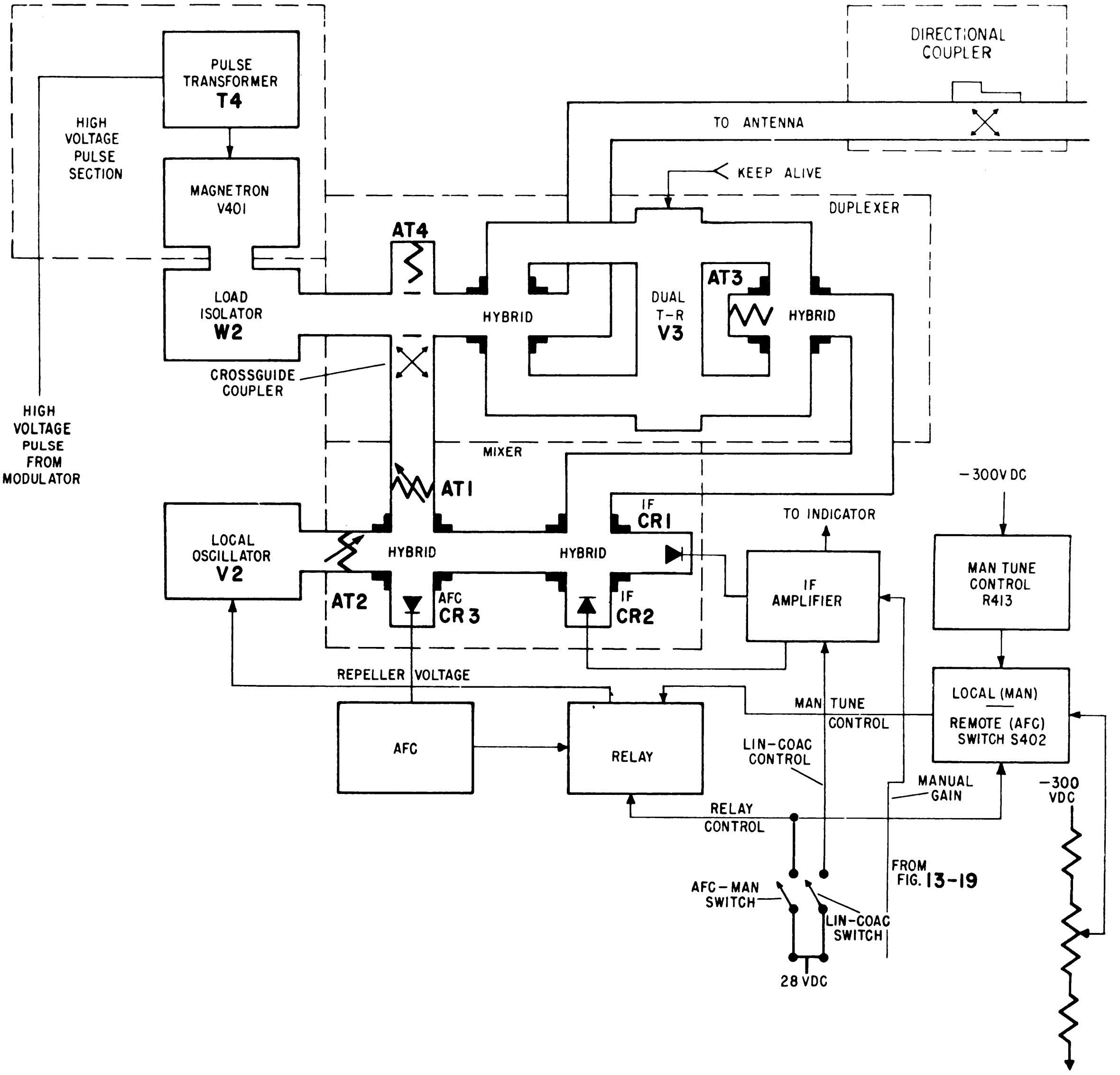


AT.349

Figure 18-12.–Transmitter and associated circuits.

permanent magnet. It allows power generated by the magnetron to be transmitted with very little loss, but will appear as a high-level attentuator to any reflected energy. This allows the magnetron to work into a matched load, thus providing very stable tube operation.

The RF energy from the load isolater enters the transmitter side the hybrid section of the duplexer. The high-level RF energy will excite TR tube V3 and ionize the gas contained therein. This ionized section will appear as a short across the waveguide, and the electrical characteristics of the hybrid will direct the reflected energy to the antenna side of the hybrid and thence to the output flange of the receiver-transmitter. Thus in the transmit condition, the



AT.350

Figure 18-13.—Waveguide assembly.

duplexer prevents the high-level RF energy from entering the receiver portion of the waveguide and directs it toward the antenna.

ANTENNA

The RF energy from the transmitter is coupled to the antenna through several sections of waveguide, a directional coupler, and a waveguide switch.

The directional coupler is a section of waveguide that provides a fitting for attaching test equipment to measure the transmitter power output and the receiver sensitivity.

The waveguide switch is used to couple RF energy from the transmitter to the antenna assembly or to an electrical dummy load.

The antenna reflector focuses and directs RF energy generated by the radar transmitter and collects the RF energy reflected from targets. The antenna also provides azimuth information to the associated indicator groups by employing a servomechanism to transfer azimuth data.

The radiated beam of energy can be elevated or lowered to cover the desired areas by manipulation of the manual-tilt control on the antenna control. This changes the tilt angle of the reflector with respect to the aircraft's fuselage or to the true horizontal, depending on whether or not the radar has tilt stabilization incorporated. The true horizontal is determined by a gyro reference system.

Tilt Stabilization

Tilt stabilization is used to correct the tilt angle of the transmitted beam of RF energy to compensate for deviations in the attitude of the aircraft, thereby maintaining the beam throughout the scanning range at the angle selected by the tilt control on the antenna control. The stabilization range on one type of radar is such that, if the tilt control is set for 0°, the beam is maintained at this angle for aircraft pitch or roll up to ±30°. If the tilt control is set for other beam angles, these limits vary accordingly. A typical tilt-stabilization system is shown in figure 18-14.

The conditions depicted in figure 18-14 resulting in the waveform shown at the left, are as follows:

1. Aircraft is entering a climb.
2. Manual-tilt control is set for zero tilt.
3. Tilt-stabilizer mechanism is functioning in response to gyro signals.
4. Scanner's instantaneous position is "dead ahead."

NOTE: The amplitudes for waveforms 7 and 8 are not drawn to comparative scale.

The tilt-stabilization system shown in figure 18-14 consists of a gyroscope unit, a servoamplifier, the resolver synchro, manual-tilt synchro, tilt-torque motor, damping signal generator, and followup synchro. The gyroscope unit is separately mounted on the aircraft structure, and the resolver synchro and the servoamplifier are mounted on the antenna frame. The tilt-torque motor, damping-signal generator, and followup synchro are contained in the tilt-servo unit mounted on the rotary section of the antenna. The manual-tilt synchro is mounted on the antenna control box.

Stabilization is effected by the use of two signals: the resolver synchro signal, and the manual-tilt synchro signal. Separate pitch and roll signals originating in the gyroscope unit are combined in the resolver synchro to produce the single resolver-synchro signal. The manual-tilt synchro signal originates in the followup synchro and provides the tilt-stabilization system with continuous information as to the tilt angle of the reflector. This signal passes through the manual-tilt synchro in the antenna control where it is modified according to the setting of the tilt control. The resolver-synchro signal and the manual-tilt synchro signal, which differ in phase by 180°, are combined at the input of the servoamplifier, and the amplified resultant, or error signal, is used to control the tilt-torque motor in correcting the tilt angle of the reflector.

RECEIVER

The typical radar receiver is an extremely sensitive superheterodyne containing circuits with bandwidth capable of passing pulses of the type emitted by the transmitter. It is important that the receiver generate as little local noise voltage as possible to avoid masking weak echo signals.

In the receive condition, the magnetron is not being pulsed and the TR tube is not fired. Energy received by the antenna is directed to

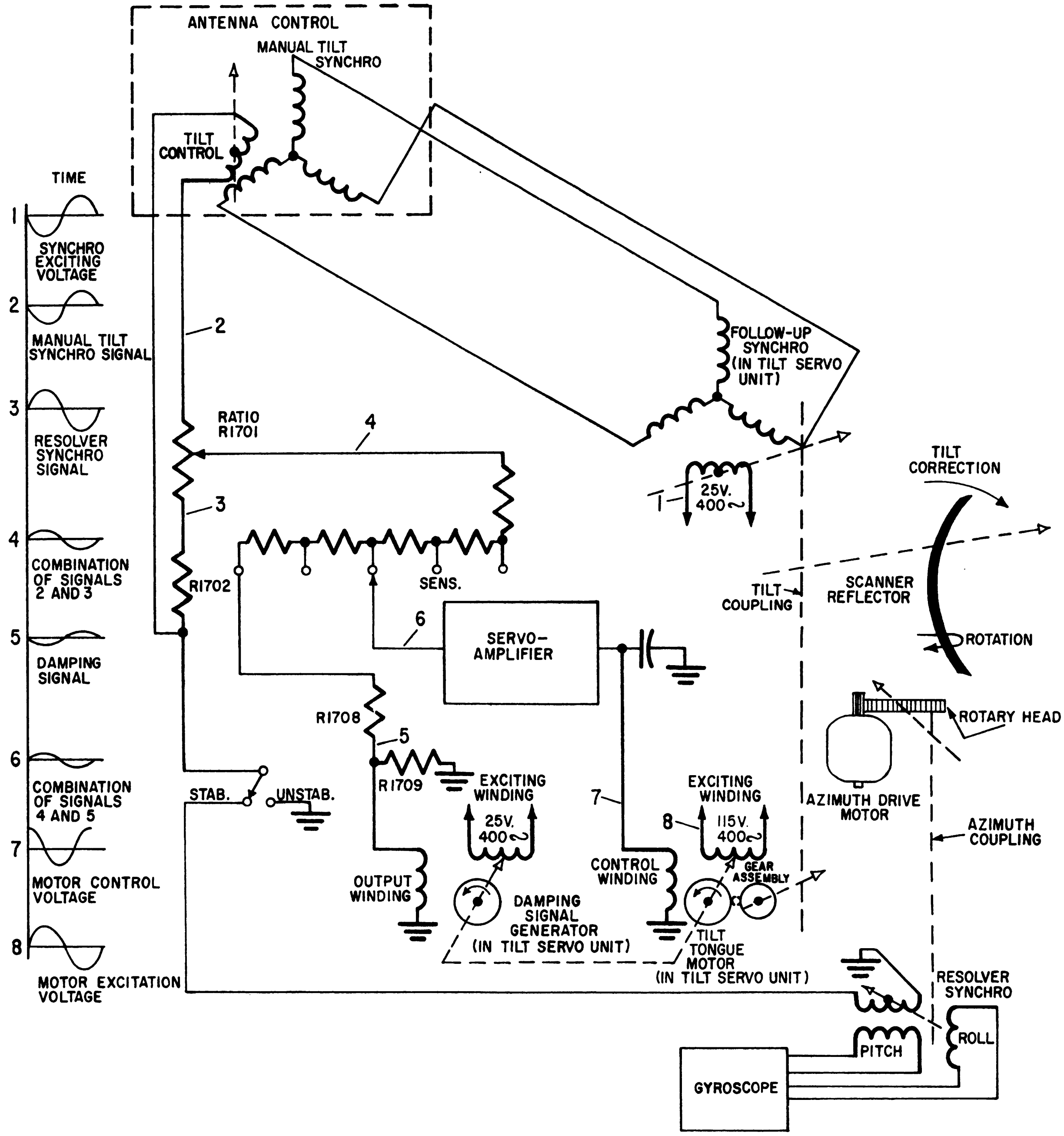


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Figure 18-14.–Antenna tilt-stabilization servosystem.

the receiver, where it enters the duplexer on the antenna side (fig. 18-13). This energy is at a very low power level; consequently, the TR tube will not fire and will appear as a continuous open waveguide. After traveling through the TR tube, the received energy enters the low-power hybrid section of the duplexer, which directs it to a crystal mixer. The electrical characteristics of the duplexer provide directivity in such a manner as to minimize received energy losses in the transmitter portion of the waveguide. Received energy is directed from the duplexer into the mixer where it is heterodyned with the output of the local oscillator (a reflex klystron) at the mixer crystals to produce the required IF of the receiver. The local oscillator is stabilized by an AFC system to keep the receiver intermediate frequency from drifting.

The IF output resulting from the mixing process is then amplified in a number of IF stages. In most aircraft radar receivers, the intermediate-frequency value is between 15 and 60 megahertz. A video detector converts the IF energy into video pulses. After passing through one or more stages of video amplification, the signals are applied to the cathode-ray indicator.

AFC System

A cross guide coupler, located on the transmitter arm of the waveguide, continuously couples a small portion of the transmitter output to a separate mixer in the receiver called the AFC mixer, to which some of the output of the klystron local oscillator is also applied. The AFC mixer develops the difference frequency of the two and applies this signal to a discriminator circuit. The disciminator output voltage is at a reference level when the correct intermediate frequency is produced. But if the receiver local oscillator attempts to drift off frequency, the discriminator produces a d-c voltage which is positive or negative from the reference level, depending on whether the local oscillator frequency is too high or too low. The d-c output of the discriminator is then applied through associated circuits to the repeller plate of the klystron local oscillator. This corrects the klystron frequency until it differs from the transmitted frequency to produce the correct IF.

IF Amplifier and AGC

The outputs of the receiver crystals in the mixer assembly are brought into the IF amplifier through coaxial lines. The IF amplifier of the receiver is a linear amplifier employing a changeover circuit, with an instantaneous automatic gain control (AGC) circuit. A relay provides the changeover from linear to COAC (clutter-operated anticlutter) when selected. Linear (LIN) operation of the receiver presents the target on the companion CRT at the true representative length and overall intensity. COAC causes the target to be presented on the indicator CRT with the leading edge of the target at normal intensity and the remainder of the target at reduced intensity. This feature allows a target to be seen which might otherwise be obscured by clutter (fig. 18-15). In LIN operation, only the land mass can be seen. However, the intensity of the land mass is reduced in COAC operation (except for the leading edge) and the otherwise obscured target can be seen.

AGC is a negative voltage applied to the suppressor grids of the IF amplifiers, except the first two and the last one, to reduce the receiver gain when signals of large amplitude and long duration are received. AGC is accomplished by detecting the negative portion of the IF pulse (fig. 18-16). The negative d-c pulses from the plate of V5 are filtered, coupled through the control relay K1 (when in COAC operation), and mixed with the manual GAIN control d-c voltage and sensitivity time control voltage (when STC is selected) on the grid of V6A.

The output is taken off the cathode of V6A and applied to RC network C3, R7 and C4. Due to the relatively long RC time constant of R7 and C3, the negative voltage pulse is not immediately applied to the AGC bus. CR1 does not conduct; it appears as a high resistance for the charge of C3. From the time the pulse starts (t1) until C3 is charged (t2), the receiver gain is essentially linear; that is, it operates with limited AGC. This allows the leading edge of any signal to be amplified at full gain before the AGC voltage is applied. Thus the output video signal consists of the leading edge of the signal at full amplitude and the remaining part of the signal at reduced amplitude. At the trailing edge of a pulse, the negative voltage on C3 and the AGC line will discharge quickly through the low forward resistance of diode CR1. In this way, the recovery time following a pulse is reduced to a minimum.

Sensitivity Time Control (STC)

STC provides reduced receiver sensitivity within a range which is variable from 0 to 45 miles from the radar set. This feature may be used to reduce clutter on the indicator CRT caused by close-in targets, such as land masses and sea return.

For STC operation (fig. 18-17) a positive trigger pulse (STC OUT), from the electrical synchronizer, is fed to the grid of V1A in the radar set control. V1A is pulsed into conduction by the input pulse. While V1A is conducting

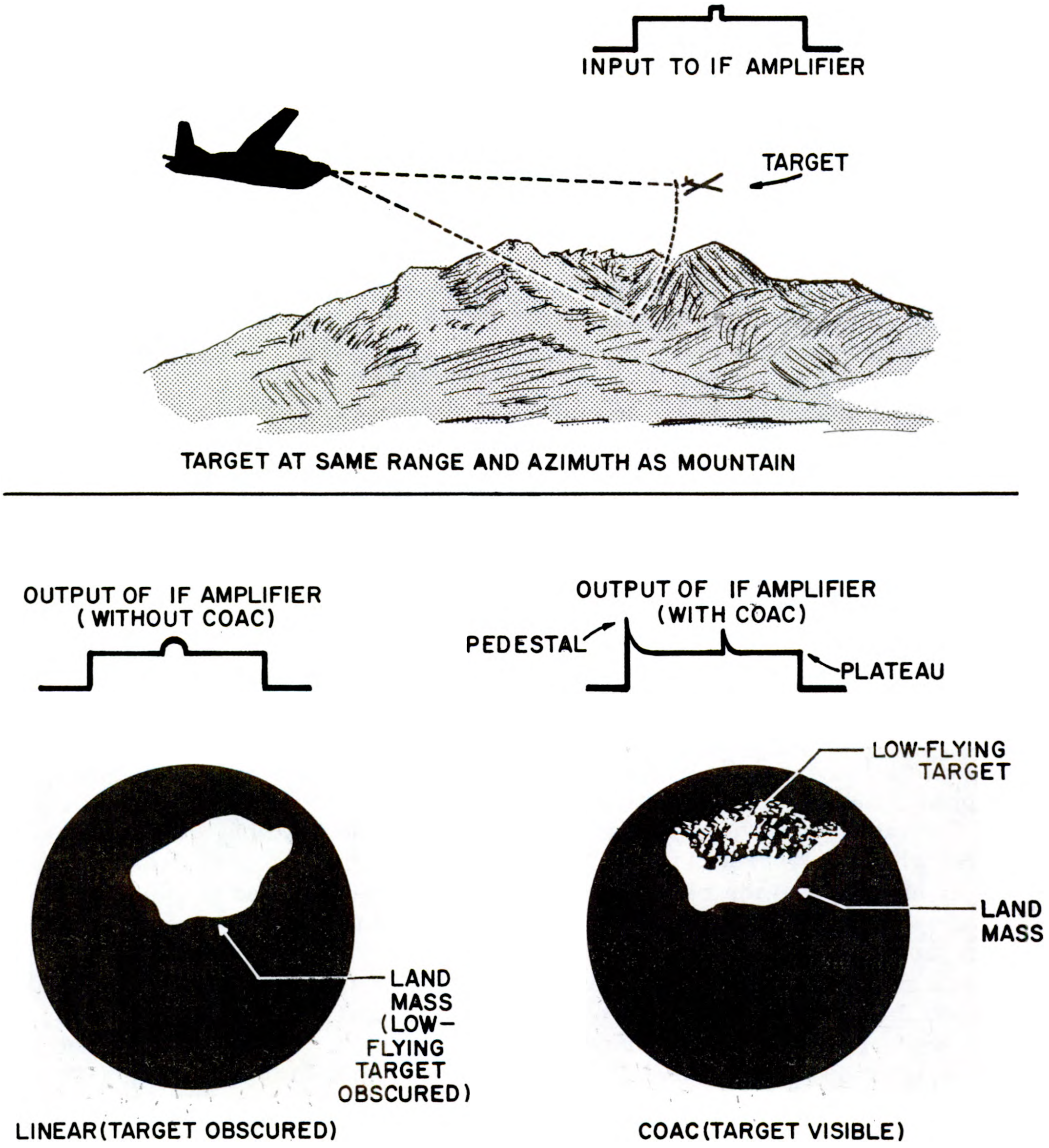
INPUT TO IF AMPLIFIER
TARGET
TARGET AT SAME RANGE AND AZIMUTH AS MOUNTAIN
OUTPUT OF IF AMPLIFIER (WITHOUT COAC)
OUTPUT OF IF AMPLIFIER (WITH COAC)
PEDESTAL
PLATEAU
LOW-FLYING TARGET
LAND MASS
LAND MASS (LOW-FLYING TARGET OBSCURED)
LINEAR (TARGET OBSCURED)
COAC (TARGET VISIBLE)

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Figure 18-15.—Linear vs. COAC operation.

capacitor C2 is charged negatively. The amount of negative voltage change on C2 is controlled by the setting of depth control (R8). The voltage magnitude controls the amount of reduction in receiver sensitivity. Following the trigger pulse, V1A is cut off and capacitor C2 discharges. The discharge time of C2 is determined by the range control setting. The exponential voltage rise from C2 is coupled through cathode follower V1B. The voltage output from the cathode follower is clamped by capacitor C4 and diode CR1 to the d-c potential provided by the manual gain control.

The exponential voltage amplitude determines the amount of reduction of receiver sensitivity and is controlled by R8, the depth control.

The length of time that the exponential voltage is present determines the range of STC and is controlled by R7, the range control.

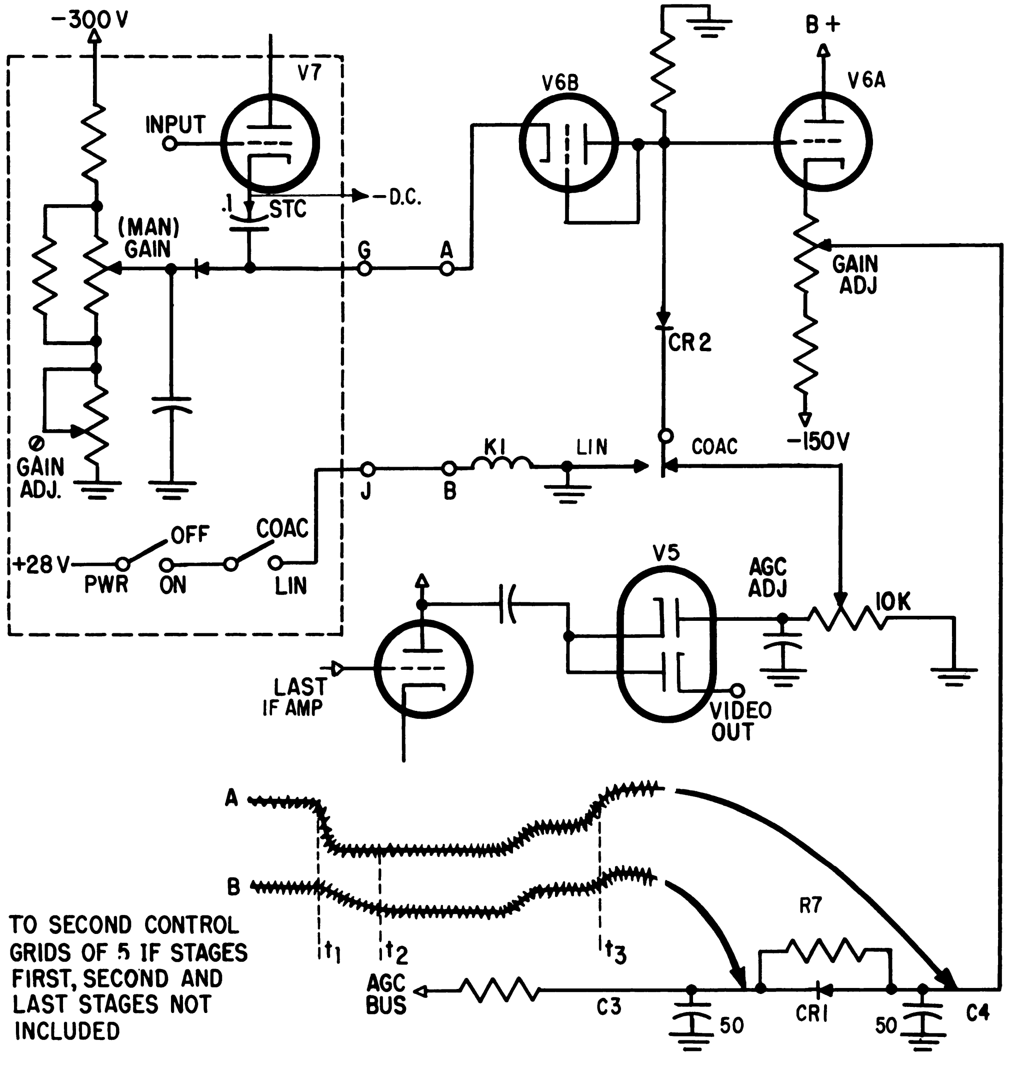

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Figure 18-16.–AGC circuit.

INDICATOR

The indicator accepts the radar data such as video pulses, range marker voltages, and sawtooth timing waves, and represents them in a visual display on the screen of a cathode-ray tube. The entire assembly contains the cathode-ray tube and various electronic circuits necessary for presenting the desired information on the screen. These circuits include video amplifiers, diode clamping tubes, and the controls for adjusting the brilliance of the visual pattern.

Sawtooth timing waves of voltage or current are applied to the deflection circuits of the CRT to produce the time trace or sweep in the pattern. The synchronizing pulse which triggers the modulator and transmitter also serves to coordinate the start of the sweep with the action of the transmitter to make range measurements

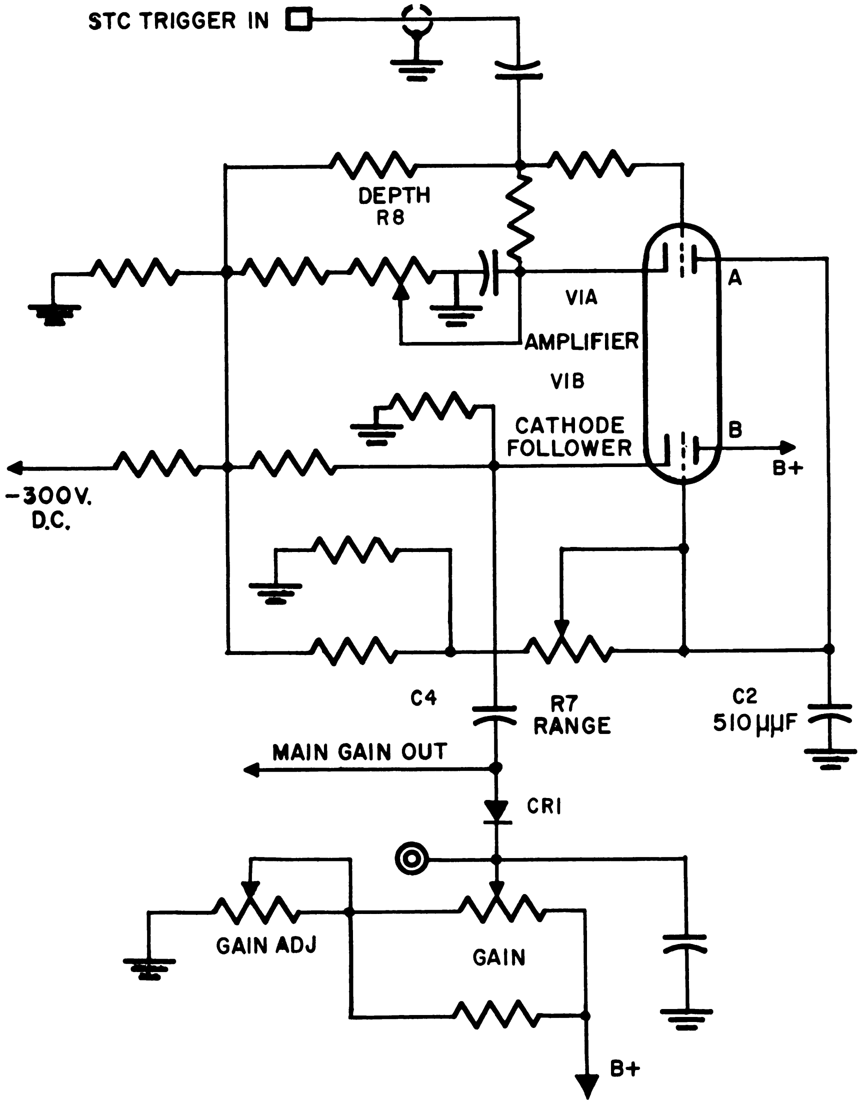

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Figure 18-17.–STC generator.

possible. Target bearing in most displays is indicated by synchronizing the position of the sweep line on the screen with the position of the antenna.

In addition to video pulses, range marker pips, and sweep voltages, a square wave pulse is applied to the indicator tube which blanks the beam between sweeps so that retrace lines do not appear on the screen.

Figure 18-18 illustrates, in block diagram form, the circuitry of a typical radar indicator for general-purpose use.

Types of Modulation

Two general types of presentation are used in aircraft radar indicators. They are the deflection-modulated and the intensity-modulated displays. The electron beam can be deflected from its normal linear sweep across the screen of a CRT. When this type of deflection is initiated by the radar echo, it is called deflection modulation. If the radar echo is caused to intensify the electron beam of the CRT without deflecting it, intensity modulation results. In both types of modulation, the range sweep is modified at a distance from its origin that is proportional to the target's slant range.

In the deflection method, the video pulse causes a momentary deflection of the cathode ray electron beam and produces a pip in the trace to indicate a target echo. In the intensity method, the video signal is applied to the element of the CRT which controls the intensity

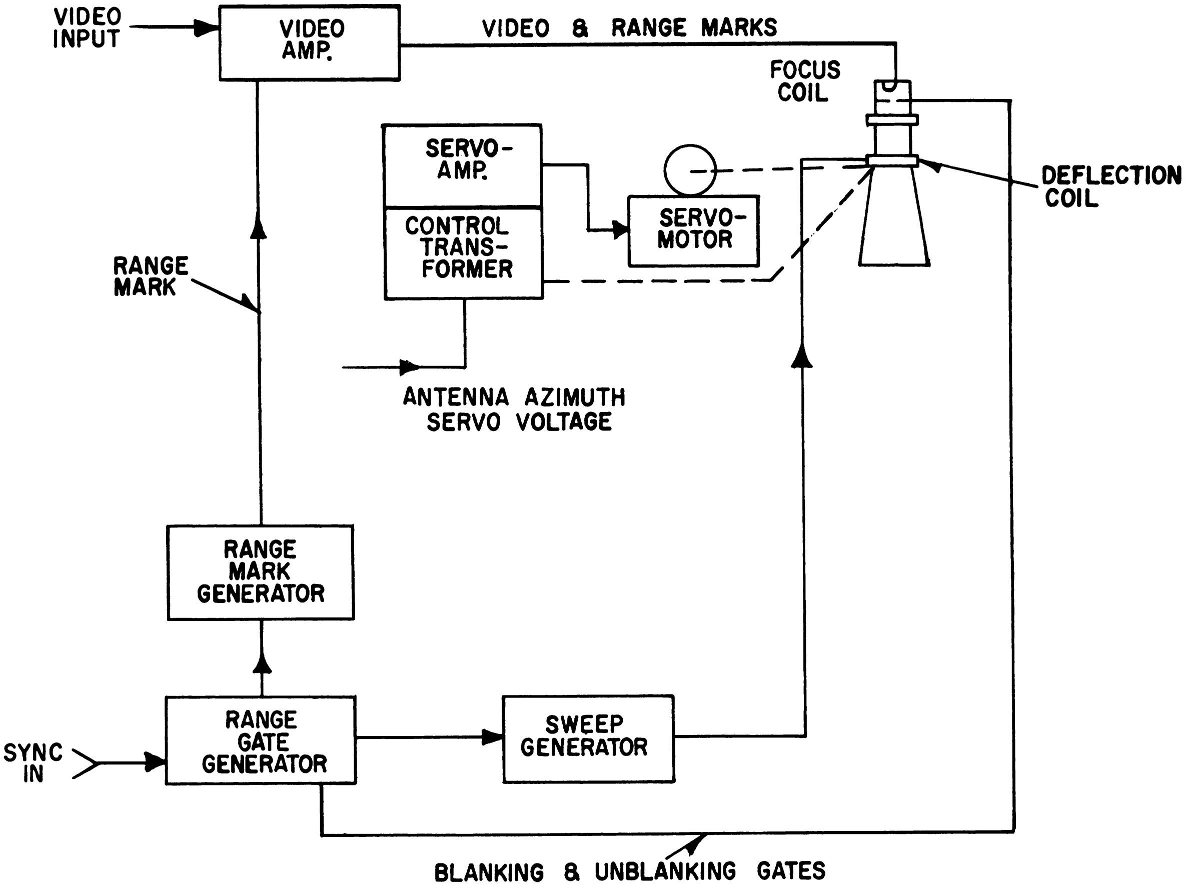

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Figure 18-18.–Radar indicator, block diagram.

of the electron beam, and the resulting target image is a bright spot of light. The A–scope is an example of the deflection method and the PPI is a typical intensity presentation.

Spatial Dimensions

Space is commonly considered to have three dimensions; that is, the position of a point in space can be described by three quantities. In terms of radar, these three quantities are slant range (distance), bearing angle (horizontal direction), and elevation angle (vertical direction). A display of information is one-, two- or three dimensional, according to the number of dimensions presented. Thus the reading of a radar altimeter is one-dimensional, and a chart or PPI is two-dimensional. When slant range, bearing, and elevation are all given on a single screen, a three-dimensional display results.

The display of a particular radar is a compromise in the emphasis to be given to the spatial dimensions. The various types of display are designated by letter–A-scope, B-scope, etc.– designation being applied to the presentation itself and, by extension, to the unit that produces it. Thus, the letters PPI are applied to a piece of radar equipment and also to the type of display shown by a plan position indicator.

The more basic facts concerning A-scopes, B-scopes, PPI, and range-height indicators (RHI) are given in Basic Electronics, NavPers 10087-B. Some of this information is reviewed in the following paragraphs, along with additional details relating the various types of scopes of aircraft utilization.

Typical Indicators

The PPI scope is one of the most common types of display for airborne radar. The CRT used in a PPI scan is intensity modulated with the sweep moving radially from the center outward. Basic Electronics, NavPers 10087-B, explains how a voltage applied to a pair of deflecting coils would cause the electron beam to move to one side of the screen, at right angles to the magnetic field. In the PPI scan the time base is applied in this manner; distance is measured from the beginning of the sweep, the center of the screen. If the deflecting coils are made to revolve slowly around the neck of the tube, in synchronism with revolutions of the directional antenna, a polar map is developed on which the range is plotted radially against the position in azimuth through 360°. The top of the screen can represent dead ahead of the aircraft, or it can be oriented to true north. In some aircraft installations it is possible to synchronize the PPI picture with the fluxgate compass so that the top of the screen represents true north.

Range markers are used with most PPI scopes. The timing system is made to produce equally spaced concentric circles about the scope center which show the distances of objects from the transmitter. Muptiples of 5, 10, or 20 nautical miles are often used.

Most PPI indicators use a pair of deflecting coils which are rotated around the cathode-ray tube to produce the rotating sweep. However,, if it is desired, it is possible to accomplish the rotation by electrical means.

Many PPI indicators have provision for what is called sector scan. Revolution of the antenna is stopped, and it is caused to move back and forth through a sector up to about 60°. The antenna scans this area at about two to three times the rate of normal revolution. Thus the search area is covered more frequently and targets are observed more distinctly.

There are two ways to view the picture seen of the PPI scope, depending on whether or not azimuth stabilization is used. With the azimuth stabilization in use, the output of the fluxgate compass is tied into the radar set. The PPI scope then becomes another remote compass indicator and the pattern on the scope is seen as it appears on a chart. The top of the scope represents either true or magnetic north, depending on whether variation has been set in.

It is easier to navigate with azimuth stabilization on. A bright line on the scope, known as the lubber line, always points in the same direction that the aircraft is heading. True or magnetic bearings are read on the azimuth scale, and the pattern on the scope is always oriented with the chart.

With azimuth stabilization off, the top of the scope represents true heading. Bearings taken are relative bearings.

A-SCOPE.–On the A-scope, only range is presented, but accurate bearings may be obtained with auxiliary aids. Ordinarily, a single line (the time base) appears across the scope. If the gain is stepped up, the time base may appear as grass, so called because it looks like grass. (The grass results from amplification of electronic noise when the gain is increased.) When a target is within range, it appears as a sort of peak (called a pip) sticking up from the line or out of the grass. For bearing, antenna rotation may be stopped at the point where the target pip is of maximum size. Bearing may then be read from a counter or dial linked to the antenna.

B-SCOPE.–The B-scope gives bearing and range in rectangular coordinates. The bearing scale is along the horizontal axis, the range scale along the vertical. This presentation is often used in fighter aircraft; the scope shows a sector of perhaps 130° or 150° ahead, with "dead ahead" represented by the center line of the scope. Since the B-scope presentation puts a pie-shaped sector into a rectangular presentation, it is distorted and does not show a "map" of the section it scans. Still, it is close enough to a map to give you a good quick picture of the situation ahead. Since small deviations in bearing become more conspicuous as the target gets closer, it is a good scope to use when closing in on a target or to avoid obstructions. The B-scope gives very good resolution in range and bearing; that is, targets very close together can be distinguished as separate targets.

RHI SCOPE.–An RHI scope is essentially a normal PPI laid on its side so that the antenna scans vertically instead of horizontally. Range is still shown radially, but the angle that was formerly the bearing angle becomes the elevation angle. The vertical plane in which the RHI scans can be rotated about a vertical axis, as the horizontal plane of a normal PPI can be tilted around a horizontal axis. In an RHI, targets in a vertical plane only are displayed. The RHI screen shows a side view of this plane (fig. 18-19), the horizontal axis showing the range in miles and the vertical axis showing directly the height of the target aircraft in feet, and not the elevation angle. Height instead of elevation angle is obtained by electronically combining the range with the sine of the elevation angle. The height scale must be increased or stretched if significiant information is to be obtained, particularly for distant aircraft. Figure (18-19) shows a height scale which has been stretched so that 5 nautical miles (30,000 feet) is equivalent to about 20 nautical miles of range.

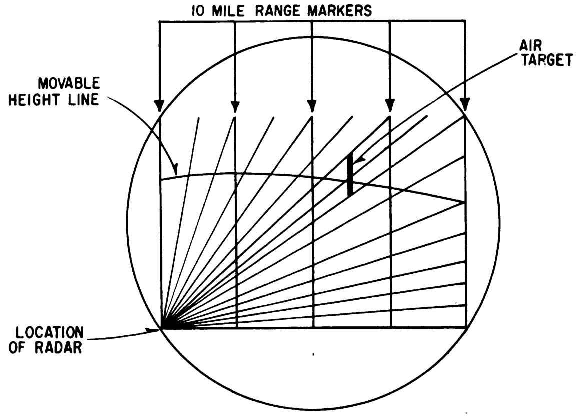

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Figure 18-19.–RHI scope presentation.

Variations in Scope Presentation

On some scopes used in aircraft all three coordinates–azimuth, elevation, and range–can be obtained. Since scopes are basically two-dimensional, the azimuth-elevation or range-elevation presentation must be superimposed on the range-azimuth presentation, with a switch to select one or the other; or one presentation may be placed above the other so that, in effect, you have two scopes.

Most radars have both long-and short-range scales, and some have several intermediate scales. The long scale may give ranges out to 100 miles or more; the short scale may be less than a mile. For instance, one type of night search and intercept radar has scales of 1,500 yards and 2, 8, 20, 50, 100, and 150 miles. Most antisubmarine warfare radar and airborne early warning radar have a maximum long-range scale of 200 miles. This scale could be very valuable in making a landfall, establishing position in off shore flight, and in the surveillance of maritime shipping.

In a number of radars, a sweep delay control makes it possible to eliminate the nearby areas from the presentation and show only the areas farther out. This is done by delaying the sweep on the scope. Ordinarily, the sweep on the scope starts at the same instant that the radar pulse is transmitted. Since the closest targets are normally those directly beneath the aircraft, there is a hole in the middle of the picture. This hole represents the distance between the aircraft and the ground. To eliminate this hole, the start of the sweep is delayed by a selected amount equivalent to the altitude. With this delay, called altitude delay, the hole is closed up and objects underneath the aircraft appear near the center of the PPI picture. Altitude delay also performs another function. As it is a measure of the distance between the aircraft and the ground or sea below, it can be used to indicate absolute altitude.

Provisions are also made for sweep delay in larger increments in order to give a more detailed picture within certain ranges. Some equipments provide altitude delay up to approximately 35,000 feet and sweep delay up to 200 miles in units of 10 miles. With a 20-mile range setting and no altitude delay, but with sweep delay set at 20 miles, the picture in this equipment would show returns from the area between 20 and 40 miles distant.

Ground Stabilization

Search radar produces a PPI display that constantly changes as the aircraft moves across an area. Since the sweep starting point represents the position of the aircraft in the center of an area, it follows that the PPI presentation will change as the aircraft travels. Also, any targets on the scope will move across the scope. If, however, a target is selected and the radar sweep is "ground stabilized," the sweep starting point will change and the targets will remain fixed in place on the scope. The radar continues to view only the selected area in which the target lies. This is accomplished by the use of auxiliary ground position indicating equipment and off-centering circuits within the indicator.

Ground position indicating (GPI) equipment continuously indicates the ground position of a flying aircraft from an initial reference point. One of its functions is to show north-south and east-west distances from the reference point on direct reading dials. Its primary function is to furnish voltages which will ground stabilize a radar sweep. The PPI sweep remains fixed geographically.

POWER SUPPLY

In airborne equipment, the primary a-c and d-c voltages are supplied from the aircraft's power system to the various units in the radar system. Within the various power supplies the voltage is stepped up or down, and if necessary rectified, to fulfill the requirements of the radar.

The power supplies used in radar are of many different types—bridge, half-wave, full-wave, voltage doubler, etc., and some have voltage regulating circuits to maintain critical voltage levels. Various types of power supplies are covered in Basic Electronics, NavPers 10087-B, and should be reviewed before you continue the study of this subject. A brief description of a typical 3-phase, half-wave rectifier is given in the following paragraphs.

The primary power supplied to most aircraft radar installations is 115-volt, 3-phase, 400 Hz. A 3-phase, half-wave rectifier acts like three half-wave rectifiers operated so that each rectifier tube plate becomes positive once every 360 electrical degrees of phase rotation. Because of the 3-phase connection of the rectifiers, the circuit will deliver a comparatively large amount of power. The output ripple voltage is 1,200 Hz, and a minimum amount of filtering is required. Figure 18-20 shows a 3-phase power supply and the wave-forms.

The waveforms show that curve 1 starts to rise from point zero. After 120 degrees, curve 2 starts to rise from zero, and curve 1 is starting to return to zero after passing through a peak. After another 120 degrees, curve 3 starts to rise from zero and, at the same time, curve 1 has almost reached a peak in the negative direction, and curve 2 is returning to zero after passing through a peak. After 360 degrees, curve 1 has returned to point zero, curve 2 has returned to point zero after passing through a positive peak, and curve 3 has almost reached a peak in the negative direction. The output waveform is a series of overlapping positive cycles of voltage that never falls below 50 percent of the voltage maximum. When this condition is compared to other forms of rectification, the reason for less filtering is readily apparent. For example, the output waveform of a full-wave, single-phase rectifier falls to zero volts once for each 180°(ripple frequency 800 Hz), and the half-wave, single-phase rectifier waveform falls to zero once each 180° and remains at zero for the next 180° (ripple frequency 400 Hz).

Since the frequency of the ripple voltage is higher, it is possible to use comparatively small filter chokes and capacitors in a 3-phase power supply. In high-power radar power supplies, gas diodes are used because of their efficiency. However, recent development of high-efficiency, heavy-duty germanium diode rectifiers has resulted in a trend away from vacuum tubes because of savings in space. In addition, no filament power is required for the germanium diodes, which results in even greater savings in space and weight.

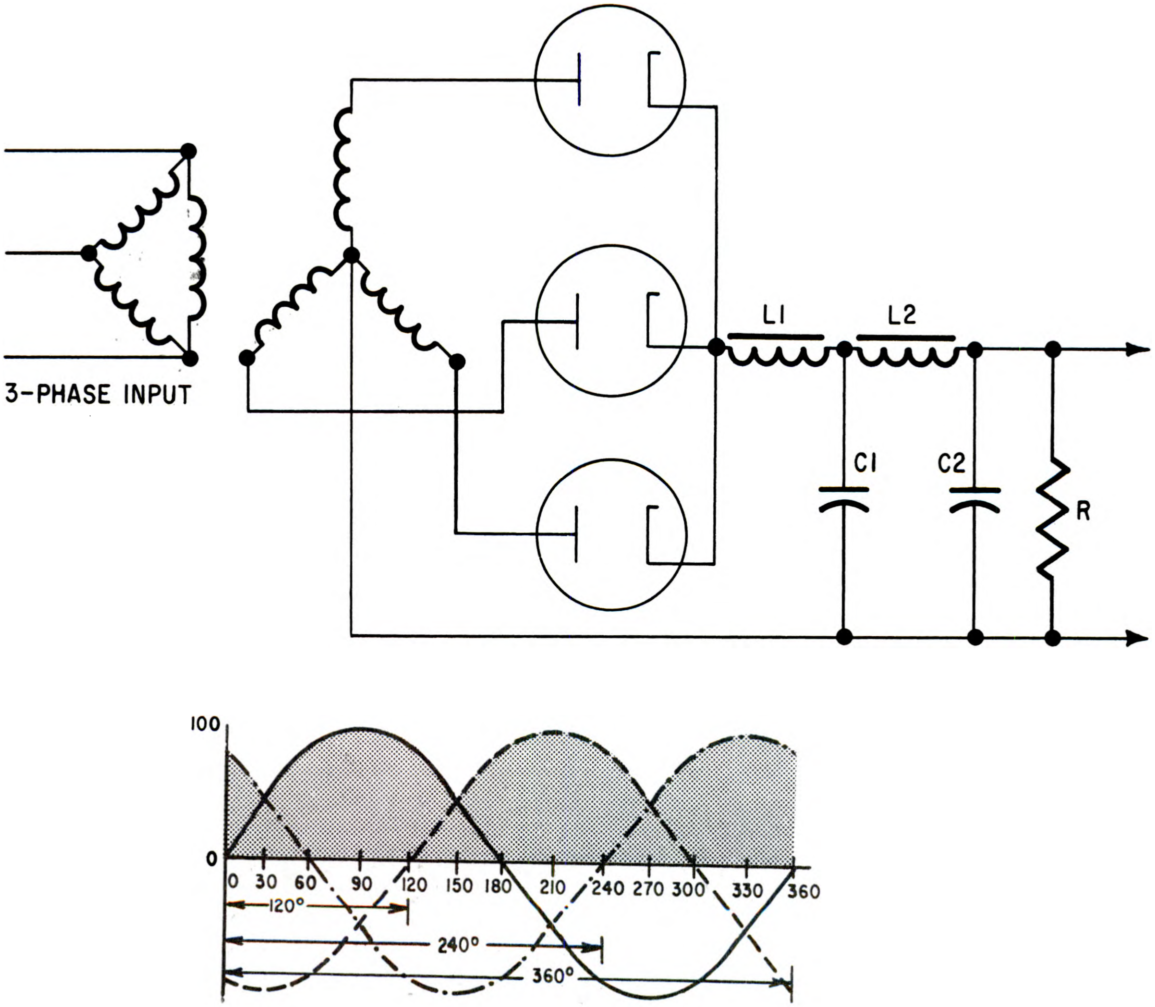

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Figure 18-20.–Schematic diagram of 3-phase power supply and waveforms.

CHAPTER 19

PRINCIPLES OF IFF

FUNCTION OF IFF

The age-old problem of distinguishing friend from enemy in warfare increased greatly when aircraft came into use. As faster ships and aircraft have been developed, the identification problem has increased. Although a radar can detect targets (both sea and air) at long ranges, it displays both friend and enemy as similar spots of light on the CRT. With the destructive power of modern weapons and the speed of modern weapon delivery systems, it is not practical to wait until the target has been identified by visual means to begin preparing for battle. Therefore, some method other than visual recognition must be used to identify the target as early as possible.

The problem of identification led to the development of an electronic system that permits a friendly craft to identify itself automatically when interrogated, before approaching near enough to threaten the security of other naval units. This electronic system is called IFF (identification, friend or foe). For operations involving only friendly aircraft, it is important to know not only their location but also the identity of each.

IFF systems are designated by MARK numbers. The IFF mark number is a Roman numeral (Mark X), to prevent possible confusion with fire control radar systems also designated by mark numbers (Mark 29, etc.).

MAJOR AND AUXILIARY UNITS

The IFF system consists basically of a pair of special transmitter-receivers, working in conjunction with a radar set. Figure 19-1 shows the units required for the basic operation of an IFF system. The system is composed of a RECOGNITION group and an IDENTIFICATION group.

The recognition group consists of an interrogator, a responser, and a coder-synchronizer. In airborne equipment, the interrogator and responser are usually contained in the same housing; this is known as the interrogator-responser (IR) unit (AN/APX-71 or AN/APX-72).

The identification group consists of a transponder and provisions for an auxiliary coder. The auxiliary coder, when installed, enables identification on a selective basis; it is thus called the Selective Identification Feature (SIF). Almost every aircraft and ship of the Armed Forces carries a transponder (such as the AN/APX-6 or AN/APX-64), since this is the unit which provides identity when challenged.

Coder-Synchronizer

The coder-synchronizer is the main unit of an IFF system; it enables the system to have three modes of operation on a time-sharing basis. The coder-synchronizer performs two functions—it generates the selected coded interrogation pulses, and separates the received video pulses into the proper channels.

INTERROGATOR.—The interrogator is a pulse type transmitter, triggered by the coder-synchronizer, which acts as the challenger. When a radar operator observes an unidentified target on the radar, he sets the interrogator in operation and it emits coded challenging (interrogation) pulses.

The challenge is a pair of UHF pulses emitted a few microseconds after the radar pulse. There are three types of challenge signals,

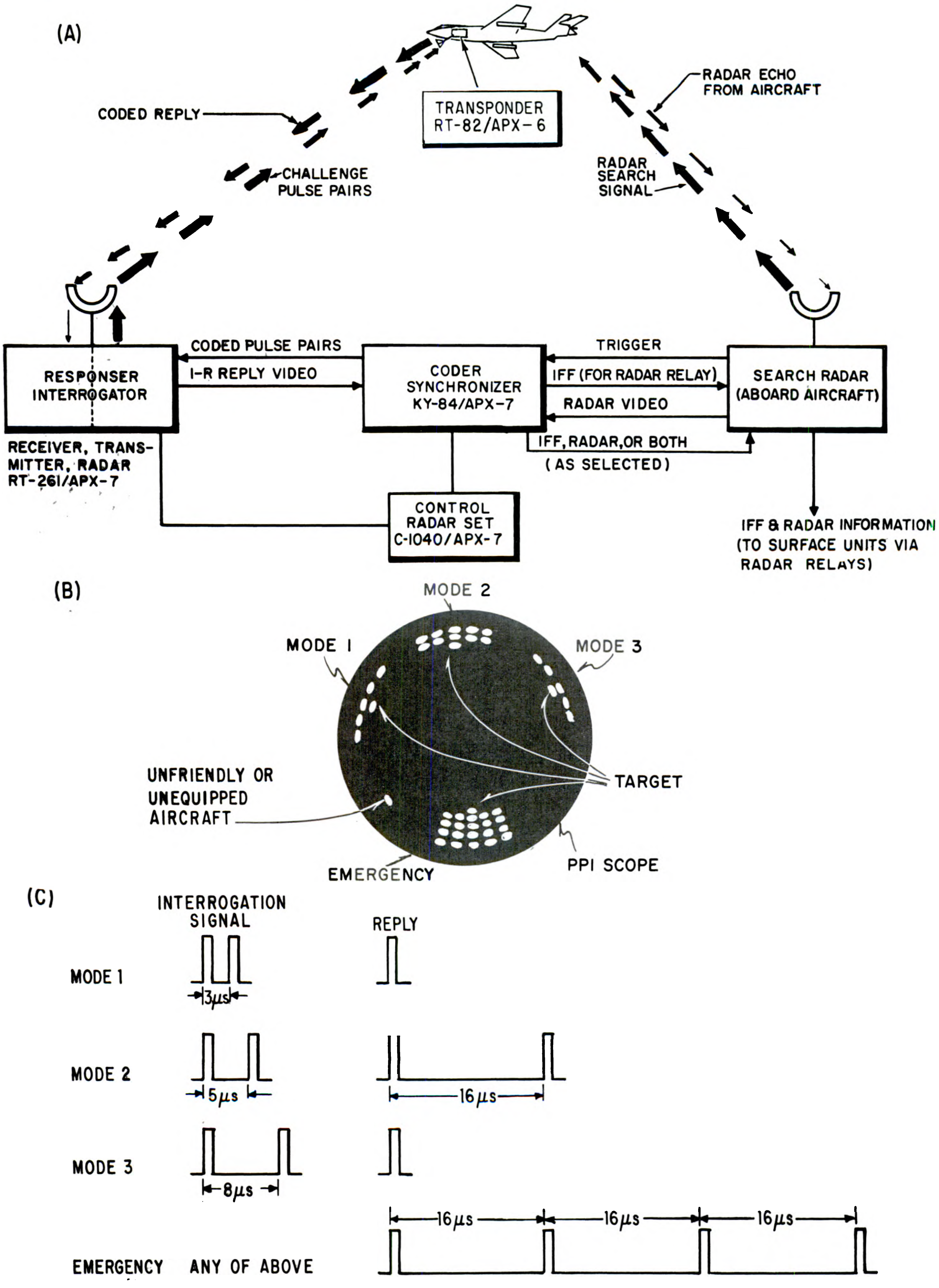

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Figure 19-1.—IFF system.

which are transmitted (when selected) on a time-sharing basis, called mode 1, mode 2, and mode 3. Each mode produces a pair of 1-microsecond pulses. In mode 1, the paired pulses are spaced 3 microseconds apart between the leading edges; in mode 2 the paired pulses are spaced 5 microseconds apart; and mode 3 has a spacing of 8 microseconds. The selection of the desired mode of challenge is done at the display station. The challenge signals are synchronized with the pulse of the associated radar, but with a delay of 0 to 40 microseconds introduced.

TRANSPONDER.–The challenge is received by the transponder, which is a pulse type transmitter-receiver unit. Upon receiving the proper challenge, the transponder automatically transmits an identifying reply. The reply is normally transmitted on a different frequency from the interrogation (challenge). The modes of interrogation for, and the response from, an aircraft's transponder (without SIF) are shown in figure 19-1. All pulses are 1 microsecond in width. All time spacing is in microseconds and is measured from leading edge to leading edge.

In airborne equipment, the pilot controls the replies to all modes except mode 1. His selection of replies to all other modes is governed by the operational procedures in use at the time.

The airborne transponder is able to generate an emergency reply for all modes of interrogation if the pilot has the proper switch enabled. The emergency reply comprises 4 pulses; each pulse is 1 microsecond in width, with 16 microseconds between leading edges.

The airborne transponder has a special mode 2 function, controlled by a three-position switch labeled I/P-OUT-MIC. With the transponder replying to mode 1 interrogations only, and the I/P-OUT-MIC switch placed in the MIC position, the transponder will not reply to mode 2 interrogations unless the pilot's microphone button is pressed for radio communications. If the spring-loaded I/P-OUT-MIC switch is held in the I/P position, the transponder will reply to mode 2 interrogations. The response for this special mode 2 is the same as that for normal mode 2.

RESPONSER.–Replies from the transponder are received by the responser in the recognition unit. The replies are converted into video pulses, which are then fed to the coder-synchronizer for separation into the correct mode channels. The output of each channel is fed to a final recognition section. The CRT may be either that of the associated radar set or a separate scope. When displayed on the radar CRT, the video pulses may be displayed separately, or they may be mixed with the radar presentation if desired. Provisions are also provided for an SIF decoder unit.

The airborne replies are shown in a PPI scope in figure 19-1 (B). They are shown as dashed lines beyond the target echo. The dashed effect is due to the mode interlacing action of the coder in the recognition unit. Blank spaces represent the time during which interrogations on the other two modes are sent out. The IFF presentation can be distinguished from the radar presentation by these dashes. The length of the dashed line varies with the range and the radiation pattern of the antenna used with the recognition (IR) unit.

Capabilities and Limitations

In the IFF system, the use of a receiver and transmitter (transponder) at the target not only serves to furnish a strong reply signal for the recognition set, but also permits replies to be made on a different frequency, eliminating clutter. Therefore, the IFF system does not require as much transmitter power as does the search radar. The additional transponder also allows the use of separate codes for replies, thereby providing for increased information. The distinctive coding used for the three modes of operation increases the traffic handling capabilities, eliminates confusion, and provides positive, rapid identification of unknown targets. In the IR unit, time sharing of the three modes permits a number of operators to use different modes without interference or delays.

Because ultrahigh frequencies are used for transmission and reception, the operation range of the Mark X IFF system is virtually limited to line-of-sight distances.

IFF will often provide recognition responses over a greater line-of-sight distance than that over which the search radar (associated with the interrogator) can respond to its own echo signals. The explanation is simple: Radar energy returned as an echo is only a very small percentage of the energy that was initially transmitted from the radar in an ever-widening beam, while the response from an IFF transponder is a much stronger signal that travels only one way–to the responser. The interrogation radar energy that strikes a distant target may be of sufficient strength to trigger the IFF transponder but not to return a usable echo. (For the purpose of this discussion, a usable signal is one having sufficient strength, when returned to the radar receiver, to be detected, amplified, and displayed as a target.) The IFF response in this case will be usable, while the radar echo will be of insufficient strength to be usable.

THEORY OF IFF

INTERROGATOR-RESPONSER AN/APX-7

The AN/APX-7 is an airborne IR unit which forms an integral part of the Mark X IFF system. It consists of Radar Receiver-Transmitter RT-261/APX-7, Coder-Synchronizer KY-84/APX-7, Radar Set Control C-1040/APX-7, and mountings.

The primary purpose of the AN/APX-7 is to challenge the identity of targets which are detected and displayed by the search radar set with which it is associated, distinguishing between friendly targets and enemy targets. In addition, the AN/APX-7 provides detailed recognition information on friendly targets for additional security and tactical purposes. Both the radar and IFF replies may be shown on the same display without compromising the radar's performance.

Functional Block Diagram

Figure 19-1 (A) is a simplified block diagram of an IFF system using Radar Recognition Set AN/APX-7. (The block diagram for a surface craft would be the same; only the components would be different.)

The search radar aboard the aircraft picks up an unknown target. The radar operator, wishing to identify this target, operates his recognition set, causing challenge signals in the form of coded pairs of RF pulses to be transmitted in synchronism with the associated radar set. If the interrogated target is equipped with an operating IFF transponder (APX-6), it identifies itself by detecting and analyzing the coded interrogation and automatically transmitting the reply signals. These replies are picked up by the recognition set, converted into video signals, and displayed on the search radar indicator. By observing this display, it is possible to determine instantly the identity of the challenged target.

Only the recognition set which transmits the challenge signal can synchronize the coded replies for useful display. Replies which are transmitted in response to challenges from other recognition sets also may appear on the radar indicator screen. However, they will be seen as random, nonsynchronous, momentary flecks of light.

The AN/APX-7 is designed so that IFF replies may be displayed on remote indicator units aboard the aircraft as well as on the search radar indicator screen. In addition, all IFF and radar information received and displayed aboard the aircraft can be made available to certain shipboard and other aircraft radars by means of an associated radar relay transmission system.

Time Sharing and Transmitting

The time-sharing function of an IFF system is accomplished by use of a coder-synchronizer. The trigger pulse (cosine pulse) from an associated radar is applied to a countdown multivibrator (fig. 19-2). The multivibrator provides one output for each input trigger, provided that the cosine's PRF does not exceed 320 pps. If the PRF is greater than 320 pps, the output will be the largest submultiple between 160 and 320 pps; for example, 500 pps in - 250 pps out.

The countdown output is then applied to three circuits–the coder (pulse pair generator), the coded IR circuits, and the triple gate generator. The pulse to the triple gate generator is either applied directly or further counted down by a counter circuit which divides the frequency of the pulse rate by a factor 2, 4, 8, or 16, depending upon the setting of switch S1001. The

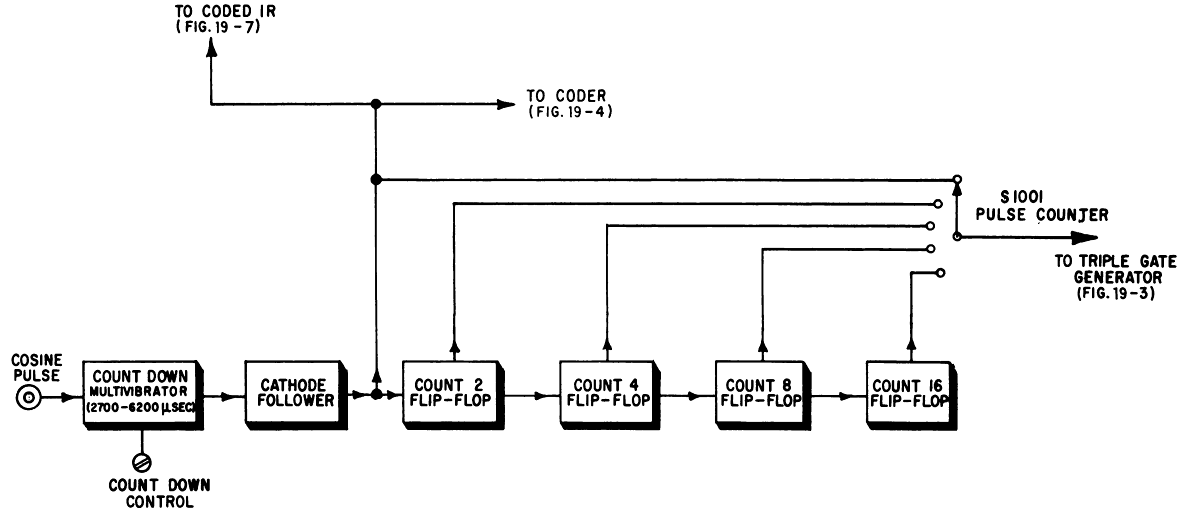

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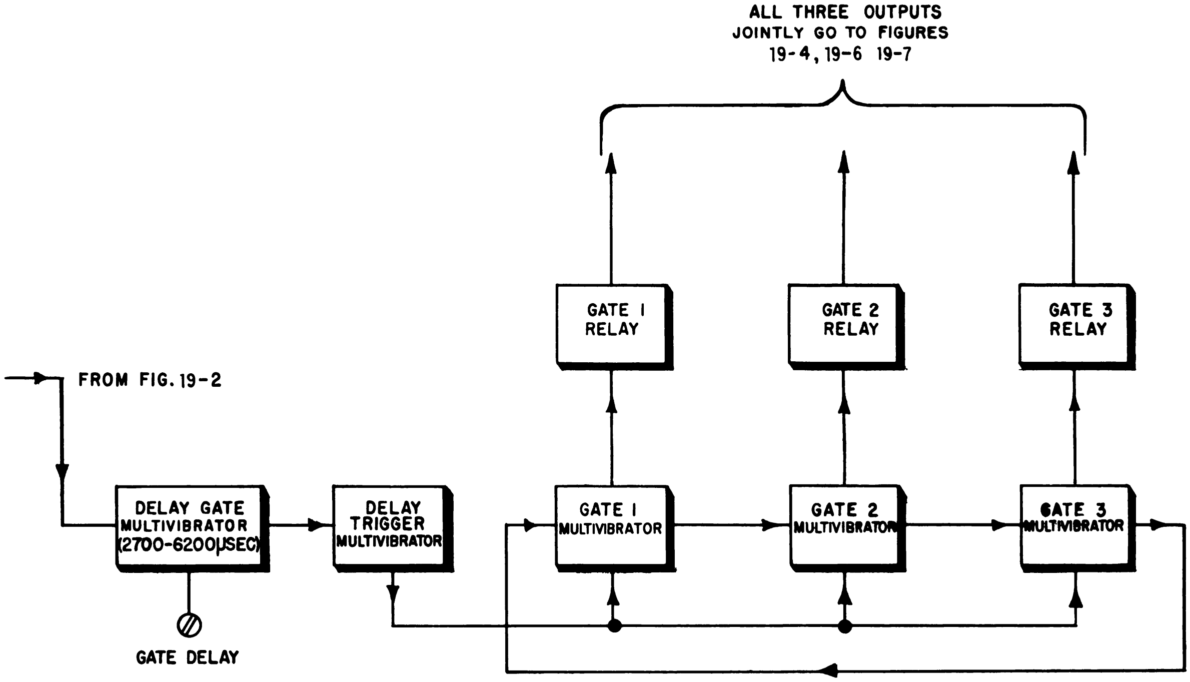
Figure 19-2.–Pulse countdown and counter, block diagram.

reason for the second countdown will be described later.

TRIPLE GATE GENERATOR.–The pulse (through S1001) triggers a delay multivibrator (fig. 19-3) whose duration (delay time) is adjustable from 2,700 to 6,200 microseconds. Since the trailing edge of the delay gate is used



AT.359

Figure 19-3.–Triple gate generator, block diagram.

to trigger the gate circuits, generation of the gate is delayed by the same period.

The purpose of this delay is to make sure that mode switching does not occur exactly when a coded pulse pair is being generated. The delay also allows sufficient time after transmission of a coded pulse pair for all replies to be picked up by the receiver. The amount of delay selected is dependent on the associated search radar range, and properly synchronizes the IFF operating range with the radar.

The gate generator furnishes three gating pulses which are used to enable use of modes 1, 2, and 3 in rotating (or time sharing) sequence. Each delayed pulse stops one gate and starts the next. Mode 1 gate starts when mode 3 ends, mode 2 starts when mode 1 ends, mode 3 starts when mode 2 ends. The duration time of each gate is a function of the type of count selected; a 1, 2, 4, 8, or 16 count may be selected (by S1001) in the counter circuit.

CODER.–The coder generates the coded pulse pairs which are fed to the modulator in the transmitter-receiver (interrogator) unit. In mode 1 the pulse generator will generate a pair of pulses that are 3 microseconds apart. Mode 2 pulses will be 5 microseconds apart and mode 3 pulses will be 8 microseconds apart. (See fig. 19-1.)

The trigger pulses from the first countdown circuit (fig. 19-2) are fed to a delay multivibrator (fig. 19-4) which provides trigger pulses that can be delayed from 6- to 50-microseconds (maintenance adjustment). This stage is used to delay the transmission of each pulse pair so that it occurs after the associated radar transmission, thereby, causing the IFF return signal to be displayed beyond the radar return target on the radar scope. The delay multivibrator would be adjusted for a delay of 40 microseconds if the associated radar had a 30-microsecond delay between the generation of the cosine trigger and the firing of the transmitter. Thus, the IFF return would be displaced 10 microseconds after the radar return target.

The output from the delay multivibrator is a positive square wave whose trailing edge triggers a blocking oscillator (fig. 19-4). The output of the blocking oscillator is a positive pulse of approximately 1 microsecond duration which appears across the cathode load resistor in the delay line (fig. 19-5).

The delay line is a lumped-constant line with taps for 8, 5, 3, and 0 microseconds of delay. The outputs from the 3-, 5-, and 8-microsecond taps are coupled to the control grids of the first-pulse-gated amplifiers (fig. 19-6) for modes 1, 2, and 3, respectively. The 0-microsecond tap is coupled to the control grid of the second-pulse-gated amplifier.

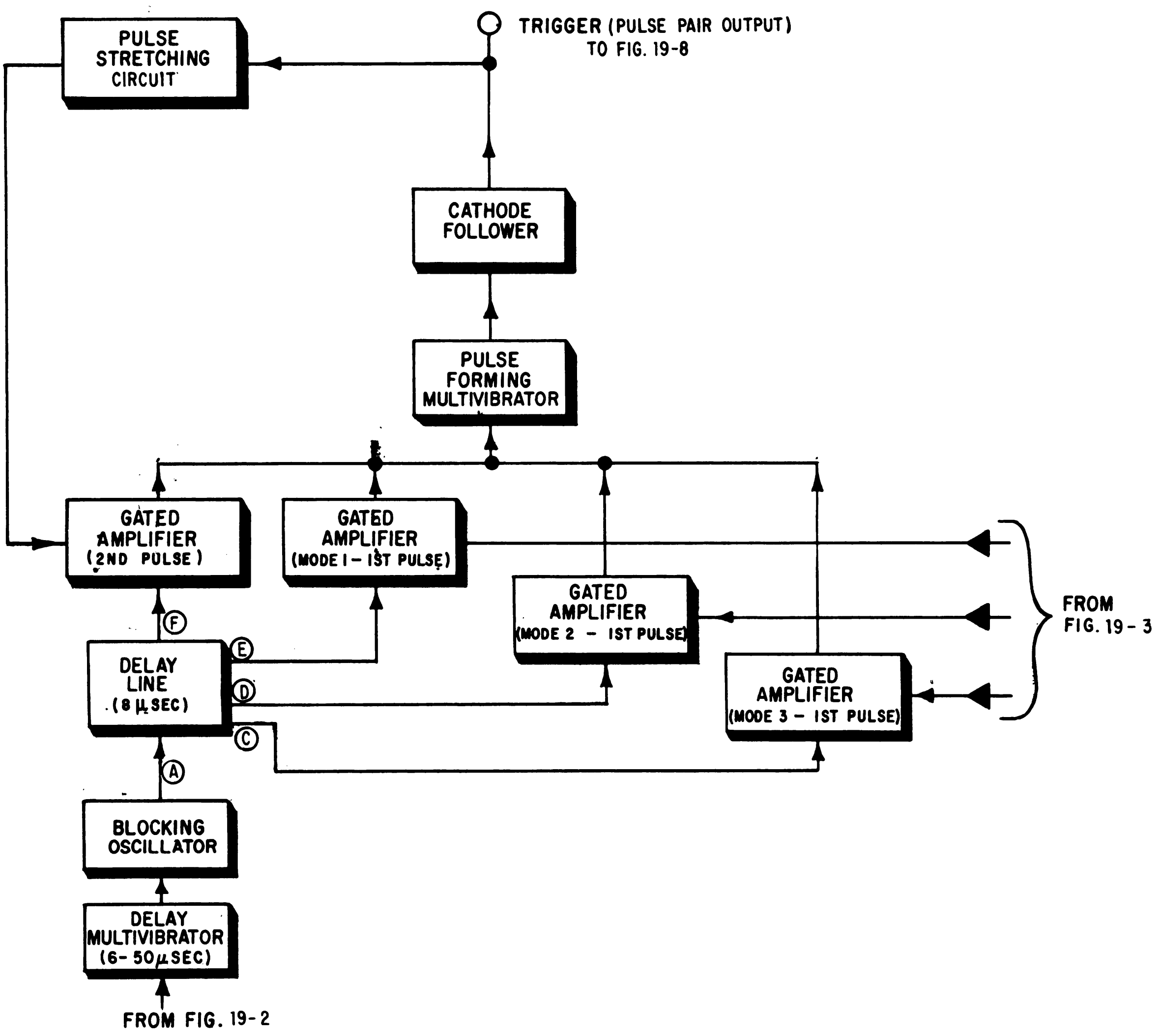
The four gated amplifiers (fig. 19-6) are coincidence amplifiers and are normally cut off by the combined negative voltages applied to the suppressor and control grids. These stages will conduct only when positive voltages are simultaneously applied to both the suppressor and control grids. The suppressor grids of modes 1, 2, and 3 first-pulse-gated amplifiers are connected to gate 1, gate 2, and gate 3 output terminals respectively (fig. 19-3) of the triple gate subassembly.

This mode-enabling gate voltage is automatically selected when the operator chooses the desired interrogation mode. The IFF control box has a rotary mode switch for selection of mode 1, 2, or 3. By selecting a particular mode, the appropriate gate relay is energized thereby allowing the positive gate voltage to be applied to the appropriate first-pulse-gated amplifier suppressor grid in the Coder and IR Coder sections.

Therefore, when a mode-enabling gate voltage is applied to the suppressor grid of one of the first-pulse-gated amplifiers, (figs. 19-4 and 19-6) the amplifier will conduct as the positive pulse from the delay line appears on the control grid. As a result, a negative-going pulse is developed across the plate load resistor, R134 (fig. 19-6). This plate load resistor is common to modes 1, 2, and 3 first-pulse-gated amplifiers and to the second-pulse amplifier.

The negative-going output pulse developed across the common plate load resistor is applied first to a multivibrator, (fig. 19-4) then to a cathode follower operated at cutoff. The cathode follower provides a low-impedance output from the coder section and for the input to the modulator of the transmitter section (fig. 19-8). The cathode follower output is also applied to a pulse-stretching network.

The pulse-stretching network consists of a very long RC network that effectively stretches the pulse width from 1 microsecond to at least 9 microseconds. The stretched pulse is applied to the suppressor grid of the second-pulse-gated


PULSE STRETCHING CIRCUIT
TRIGGER (PULSE PAIR OUTPUT) TO FIG. 19-8
CATHODE FOLLOWER
PULSE FORMING MULTIVIBRATOR
GATED AMPLIFIER (2ND PULSE)
GATED AMPLIFIER (MODE I - IST PULSE)
GATED AMPLIFIER (MODE 2 - IST PULSE)
GATED AMPLIFIER (MODE 3 - IST PULSE)
FROM FIG. 19-3
DELAY LINE (8 μSEC)
F
E
D
C
A
BLOCKING OSCILLATOR
DELAY MULTIVIBRATOR (6-50μSEC)
FROM FIG. 19-2

AT.360

Figure 19-4.—Delay multivibrator, block diagram.

amplifier (fig. 19-5 and 19-6). Thus, this amplifier will conduct when the delay-line pulse (in moving along the delay line) reaches the 0 delay tap and is applied to the grid of the second-pulse-gated amplifier. The second-pulse-gated amplifier will develop the second negative going pulse across the common amplifier load resistor R134. This pulse is also applied to the pulse forming multivibrator, cathode follower, and the coder section output. For every first pulse generated, a second pulse is also generated. A third pulse can not be generated even though the second pulse is returned thru the stretching network because there is no positive pulse applied from the delay line. The pulse pair is generated only at the PRF rate of the count down multivibrator (fig. 19-2).

In summary, refer to figures 19-4, 19-5, and 19-6. In mode 3 operation and with a single pulse appearing at Ⓑ, the following occurs:

1. The pulse will appear at point Ⓒ.
2. Point Ⓒ is connected to the grid of the first-pulse-gated (mode 3) amplifier. This amplifier will conduct because the positive gating voltage (mode 3) has been applied to its suppressor grid.

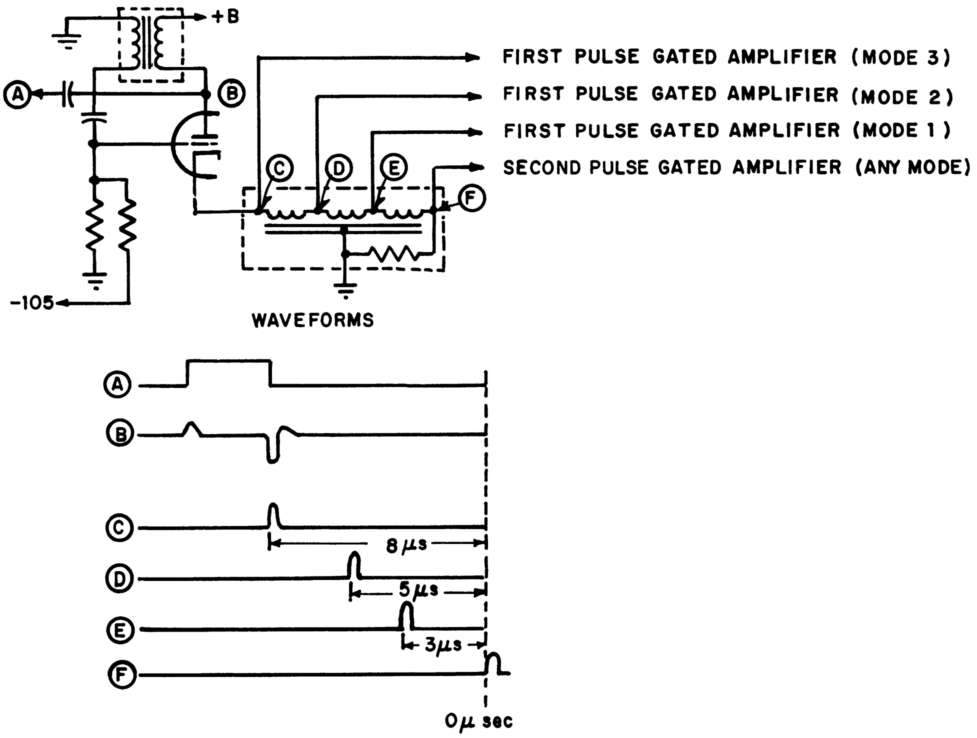

+B
Ⓐ
Ⓑ
FIRST PULSE GATED AMPLIFIER (MODE 3)
FIRST PULSE GATED AMPLIFIER (MODE 2)
FIRST PULSE GATED AMPLIFIER (MODE 1)
SECOND PULSE GATED AMPLIFIER (ANY MODE)
Ⓒ
Ⓓ
Ⓔ
Ⓕ
-105
WAVEFORMS
Ⓐ
Ⓑ
Ⓒ
8 µs
Ⓓ
5 µs
Ⓔ
3 µs
Ⓕ
0 µ sec

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Figure 19-5.–Blocking oscillator and delay line.

3. The output from this amplifier creates the first pulse as well as applying it to the pulse stretching circuit. The stretching output places a positive voltage on the second-pulse-gated amplifier suppressor grid. The second-pulse-gated amplifier is now in a condition to conduct when the delay line pulse reaches point Ⓕ and is applied to its grid.

4. As the pulse passed thru points Ⓓ and Ⓔ, the first-pulse-gated amplifiers of modes 1 and 2 could not conduct because there was no positive gating voltage applied to their suppressor grids.

5. After a total of 8 microseconds, from point Ⓒ, the pulse arrives at point Ⓕ.

6. The pulse at point Ⓕ will cause the second-pulse-gated amplifier to conduct because the stretching circuit is holding a positive voltage on its suppressor grid. The second pulse now appears across the common load resistor 8 microseconds after the first pulse.

7. If the operator had interrogated mode 2, rather than mode 3, as the delay-line pulse reached Ⓓ, it would have created a mode 2 first pulse rather than the previously mentioned mode 3 first pulse resulting in a coded pair of pulses that are 5 microseconds apart. In mode 1 operation the coded pair would have been 3 microseconds apart.

CODER IR CIRCUITS.–The coder IR subassembly (fig. 19-7) accepts triggers from the first countdown (fig. 19-2), together with the mode-enabling gate pulse from the triple gate circuit (fig. 19-3), and generates three distinctive "coded IR" pulses, one for each mode of operation.

The coded IR pulses occur 15, 20, and 25 microseconds after the trigger which is used to actuate this circuit for modes 1, 2, and 3, respectively.

The selected IR pulse and corresponding IFF video are fed to video time-sharing circuits in the associated radar synchronizer. There they are mixed with data transmission generated in the synchronizer and fed to the relay link. The ONLY function of the coded IR pulses is to permit selection and display of the correct video

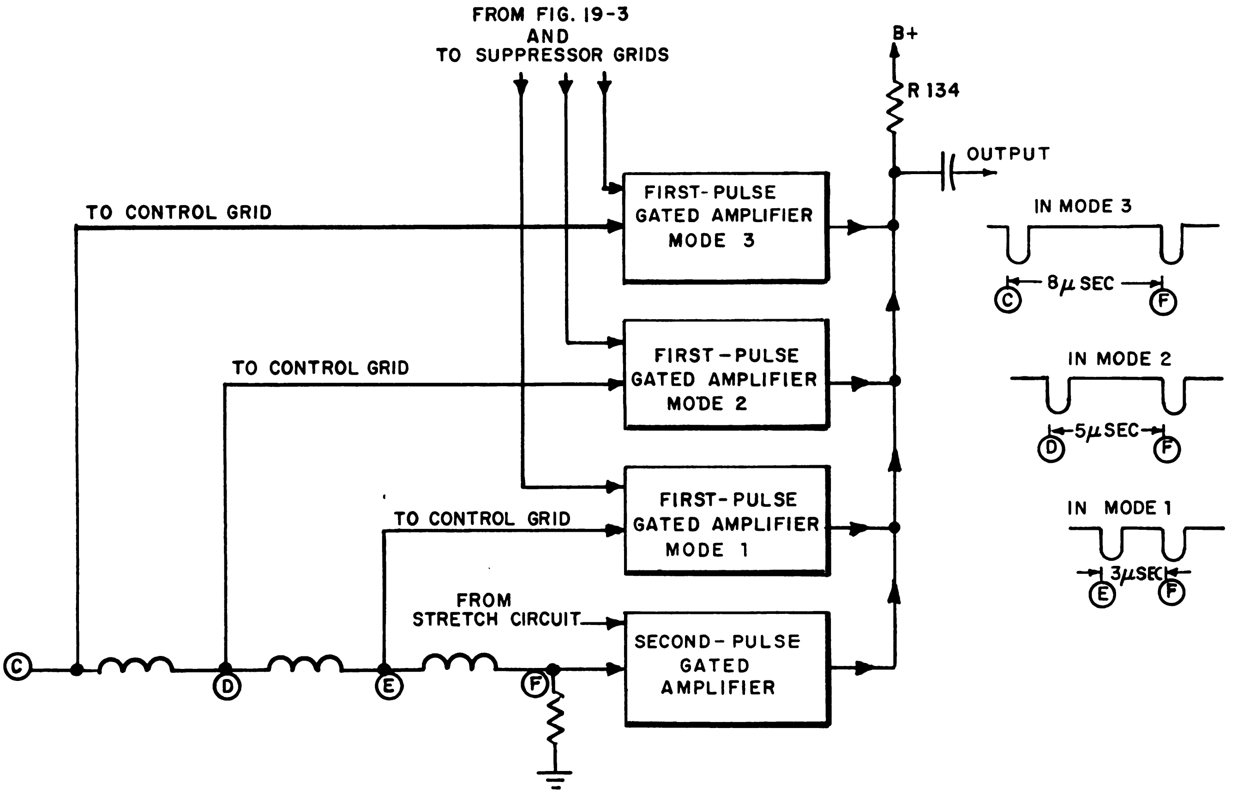

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Figure 19-6.—Pulse pair generator (coder).

at the remote indicator through a relay data system.

UHF TRANSMISSION.—The UHF transmitting section generates, modulates, and transmits coded RF challenge pulse pairs. Figure 19-8 is a simplified diagram of the transmitting section. This section consists of transmitter multiplier Z202, modulator Z102, frequency converter transmitter Z101, and the required power supplies.

The transmitter multiplier subassembly contains a crystal oscillator (V206) and necessary amplifiers and frequency multipliers (V207 through V210) to provide a signal at the required frequency between 336.3 MHz and 343.3 MHz. The output of the transmitter multiplier subassembly is fed to the frequency converter subassembly.

V211 functions as a tripler with the cathode-grid line tuned in the frequency range of 336.6 MHz to 343.5 MHz, and the grid-plate line to the final output of 1,010 MHz to 1,030 MHz.

The input pulse pairs fed to the modulator are positive trigger pulses delivered by the coder subassembly of the coder-synchronizer. These pulses are applied across the primary of a step-up input transformer T401. The transformer is connected in such a manner that the voltage pulses applied to the grid of driver stage V401 are of positive polarity. V401 is biased below cutoff by the negative voltage on its control grid. The pulses appearing at the output of T401 have an amplitude of approximately 160 volts, which drives V401 into heavy conduction. Since the tube is biased below cutoff, and is driven to saturation by the applied pulse, the output is effectively clipped and is essentially a square waveform. The output of V401 is transformer coupled to V402 by means of interstage transformer T402. V402 employs a circuit similar to V401 and develops its output pulse across the primary of T403, a phase inverting, pulse modulation transformer which has two output taps.

The outputs from T403 furnish high-level pulse modulation of the AN/APX-7 transmitter. There are two outputs from T403–a low-voltage pulse pair, approximately 300 to 400 volts; and a high-voltage pulse pair, approximately 2,400 volts. The low-voltage pulses furnish plate voltage for V208, V209, and V210 in the transmitter multiplier. The high-voltage pulses furnish plate voltage to the high-power drivers and output stage (V211 through V214).

Coils Z401, Z402, Z210, and Z211 serve two important functions. The first is their action as peaking coils, isolating the capacitance of the transmitter tubes from the modulator output, thereby improving the video waveform which is applied to the plates of the transmitter tubes. Second, they delay application of the video pulses to the plate until the RF energy in the grid circuit has a chance to build up to its maximum value.

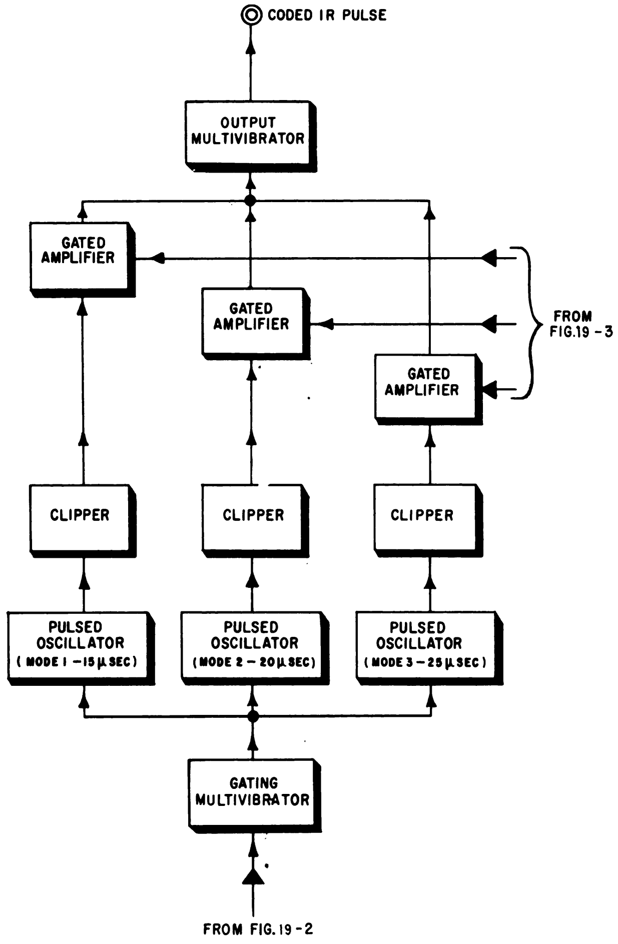

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Figure 19-7.–IR coder.

The high-power stages of the transmitter consist of coaxial line type cavities using 2C39A lighthouse tubes. The coaxial line type cavity has a high inherent Q and low radiation, making isolation of circuits relatively easy.

Each 2C39A employs two coaxial line cavities, each electrically equal to approximately one-quarter wavelength at the desired operating frequency. One cavity forms the cathode-grid circuit while the other forms the grid-plate tank circuit. Thus, each stage constitutes a grid-separation amplifier with grounded grid. RF excitation is applied to the cathode-grid input circuit, and output is taken from the grid-plate line. Exact tuning for the particular operating frequency is accomplished by means of an adjustable tuning ring in the grid-plate line. (See fig. 19-9.) This ring acts as a variable capacity which effectively lengthens or shortens the cavity according to the frequency being used.

Figure 19-9 shows the physical construction of the 2C39A circuit used in this equipment; figure 19-10 shows the electrical equivalent of this circuit. As seen in these figures, the input RF power is fed to the circuit via a coaxial line whose center conductor extends into the grid-cathode line. RF power developed in this cavity is then amplified by the tube and appears in the grid-plate line. Note that there is no direct coupling between the grid-cathode and grid-plate lines although a common grid line is used. This is true since, at microwave frequencies, current flows only at the surface of the conductor. Consequently, the cathode-grid current flows only on the INNER SURFACE of the grid line. Plate-grid current flows only on the OUTER SURFACE of this line. There is essentially no coupling (at microwave frequencies) between the inner and outer surfaces of the line.

The RF power developed in the grid-plate line is picked up by a loop connected to the inner conductor of a coaxial line at the output of the cavity. This coaxial line transmits the energy to the next stage, where similar construction is used.

The output of the final amplifier V214 is loop coupled to the antenna by means of antenna coupling post Z207A (fig. 19-8) which is mounted between the grid-plate cavity of V214 and first preselector Z207B. The antenna coupling is used

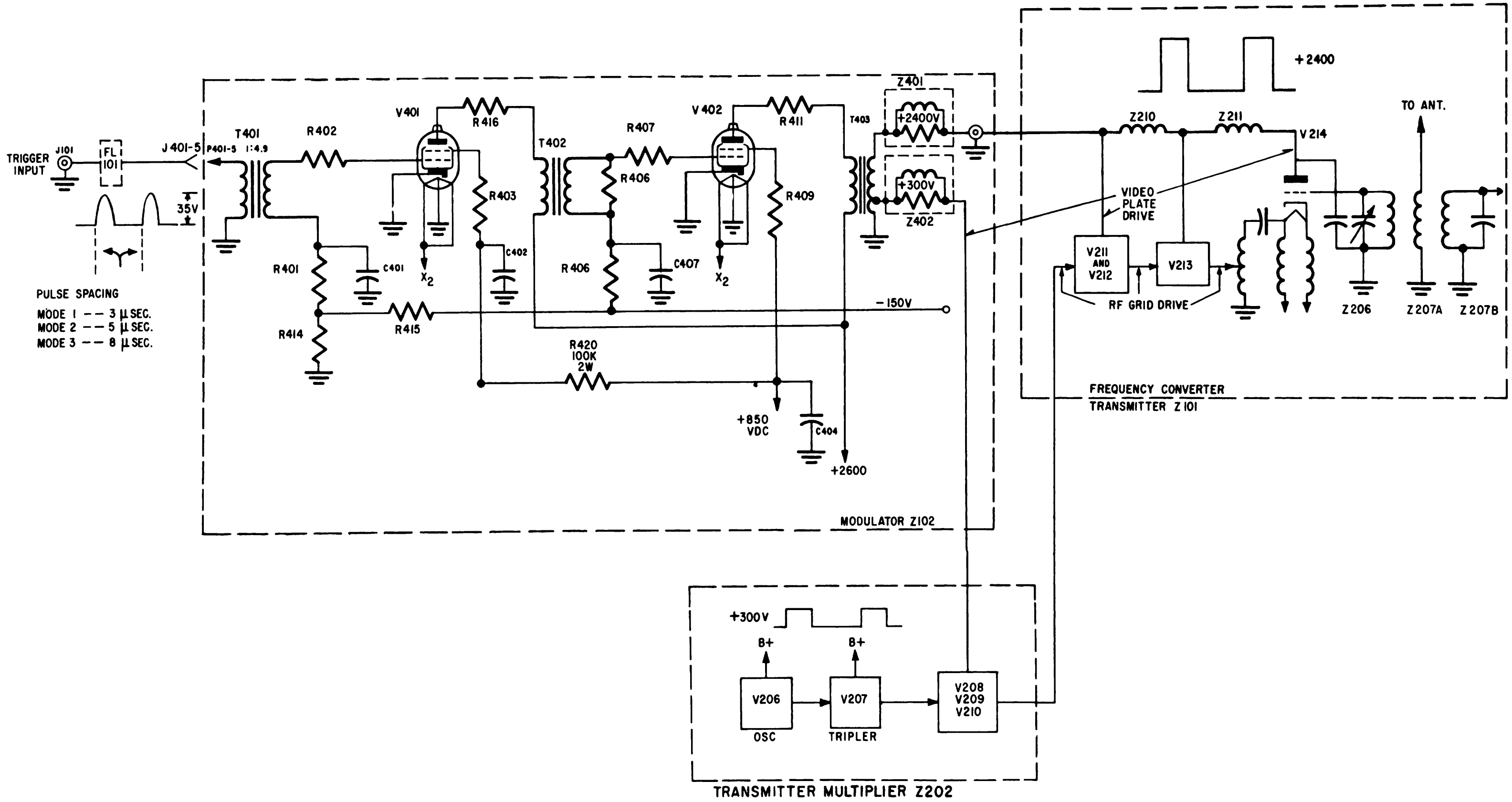

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Figure 19-8.—Simplified diagram of a transmitting section.

for transmission of V214 output and for reception of a response.

DECODING CIRCUITS.–The IFF replies are picked up and detected by the receiver in the IR unit. The mixed video signals (all three modes) are fed to the input circuit of the video separator subassembly (in the coder-synchronizer). The video separator performs the function of separating the IFF video pulses into three channels, one for each mode.

The function of the video separator is illustrated by the block diagram in figure 19-11. Amplifying is done by a dual stage amplifier that operates without any phase reversal of input to output. A schematic diagram of the amplifier is shown in figure 19-12. The video pulses from the receiver are applied to the cathode of a grounded-grid amplifier. The signal is taken off the plate and applied to the grid of a cathode follower. The input to the cathode follower is limited by V1502A, so that the output does not exceed 6 volts. The output of the cathode follower is applied to the grids of modes 1, 2 and 3 separators and to another cathode follower. (See fig. 19-11 also.) The separators for modes 1, 2, and 3 are biased considerably below cutoff, and the video pulses alone are not enough to cause conduction. Each separator is controlled by a time-shared, positive-going square wave through a gating diode circuit.

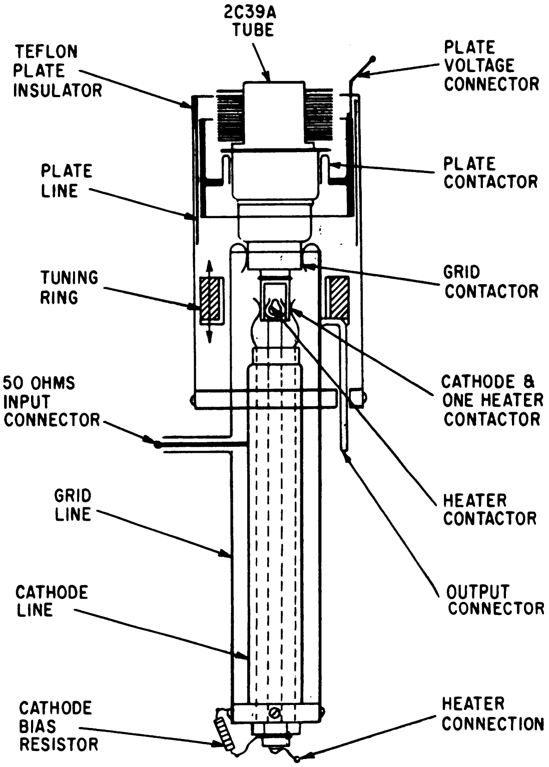

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Figure 19-9.–Type 2C39A, tube and cavity, simplified.

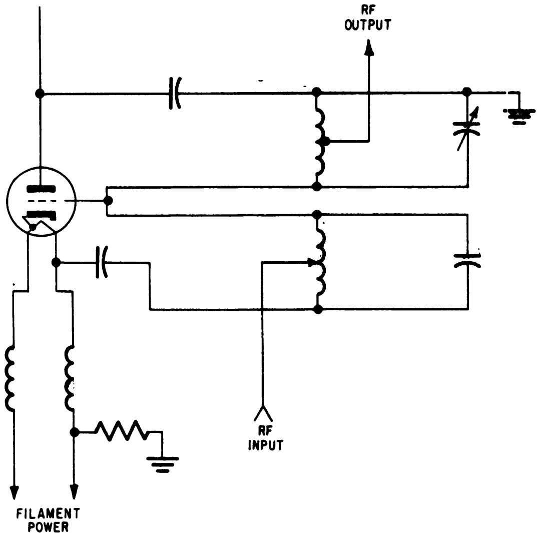

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Figure 19-10.–Type 2C39A, equivalent circuit.

Mode 1 separator and gating diode are shown in figure 19-12. Modes 2 and 3 separator circuits (not shown) are similar to mode 1.

When a gate voltage is applied to V1503, a cathode follower, the tube can conduct. During the time of the gate voltage, any video pulses coupled to the grid of V1503 from the cathode of V1501 will appear across the cathode load resistor (R1513) of V1503. (Load resistors are front panel mounted potentiometers.)

For the period of time during which a gate voltage is applied to V1503, it is also applied to the mode 1 channel of the interrogator. For this period of time the interrogator will issue only mode 1 challenges; in this manner, only mode 1 replies will appear at the output of V1503.

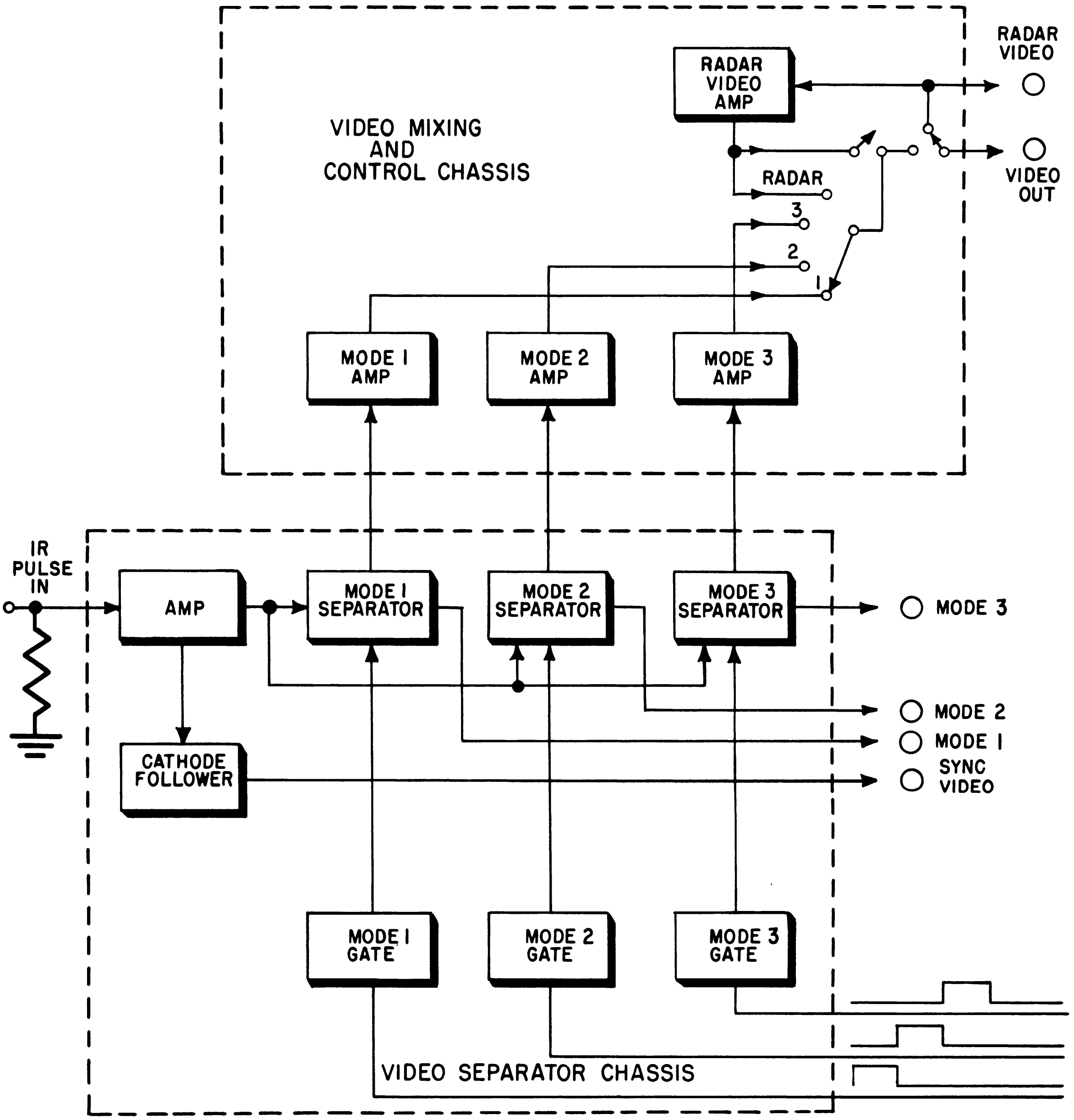

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Figure 19-11.–Video separator, block diagram.

TRANSPONDER AN/APX-6

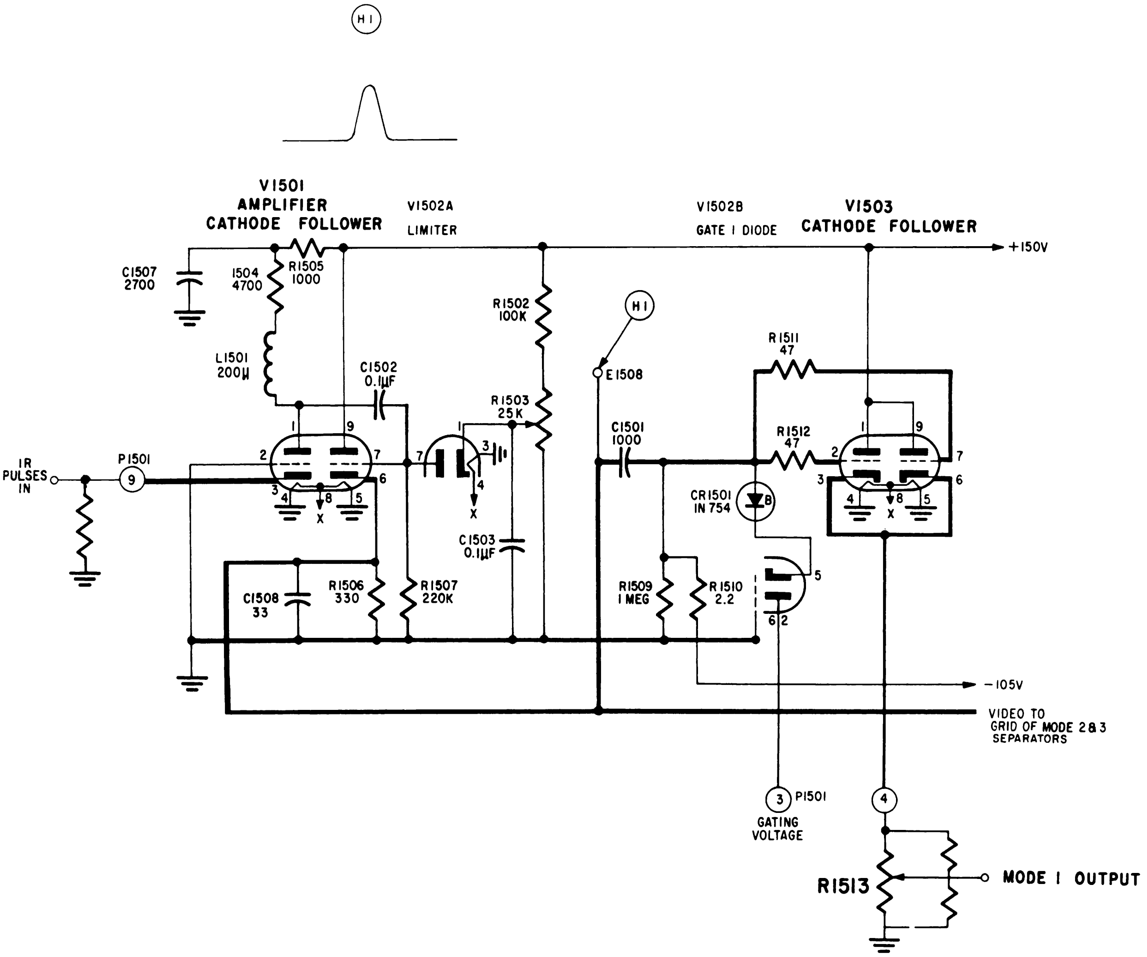
There are several different Mark X aircraft transponders in use, according to the type of aircraft in which they are installed. They all perform the same function and are basically the same electrically. The only differences are different layout of construction (to fit a given space); single unit; or combination with other systems (sharing a common power supply and housing) for the conservation of weight and space.

Functional Operation

The function of an IFF transponder may be more easily understood by referring to the simplified block diagram (fig. 19-13) in connection with the following description. The main signal channel, which is indicated by heavy lines, is arranged in the form of a loop, using a common omnidirectional antenna for reception and transmission. The equipment contains a superheterodyne receiver with broad bandwidth characteristics. The output of the receiver actuates a pulse type transmitter through a decoder and a reply pulse generating circuit.

Interrogation pulses received by the antenna pass through the preselector to the crystal mixer, where they are mixed with the output of the local oscillator. The output of the crystal mixer is filtered to remove the RF components and is fed to the IF amplifiers.

Six stages of amplification are used, in which degenerative feedback and other broadband methods provide wide bandwidth characteristics. Automatic-overload-control (AOC) and automatic-volume-control (AVC) voltages act on some of the IF amplifiers to progressively reduce the gain under conditions of excessive rate of interrogation or high levels of signal. The AOC is intended to prevent overloading of the equipment and also to maintain effectiveness of transponder operation in areas of heavy interrogation, where it is more important that the



AT.368

Figure 19-12.–Amplifier, mode 1 video separator.

transponder reply to nearby than to distant interrogation. The AVC is intended to reduce the harmful effects of CW jamming. To minimize the effects of strong echo pulses which, in conjunction with other signals, might falsely trigger the transponder, suppression circuits are included in the IF strip.

A diode detector demodulates the IF pulses, and the resulting video pulses are amplified first by two video stages in the IF strip, and then by three video stages, one of which is also a spike discriminator. The AOC/AVC voltages also bias the diode detector to produce the same effects as in the IF amplifiers.

A differentiating circuit, part of the first video stage, decreases the width of single pulses that might falsely trigger the decoders, and also minimizes the effect of strong off-tune interference.

Three decoder circuits block the main channel to all signals except the pulse pair signals with the proper characteristics. Setting the master switch of the radar set control to EMERGENCY automatically insures that all three decoders are operated by their correponding interrogations.

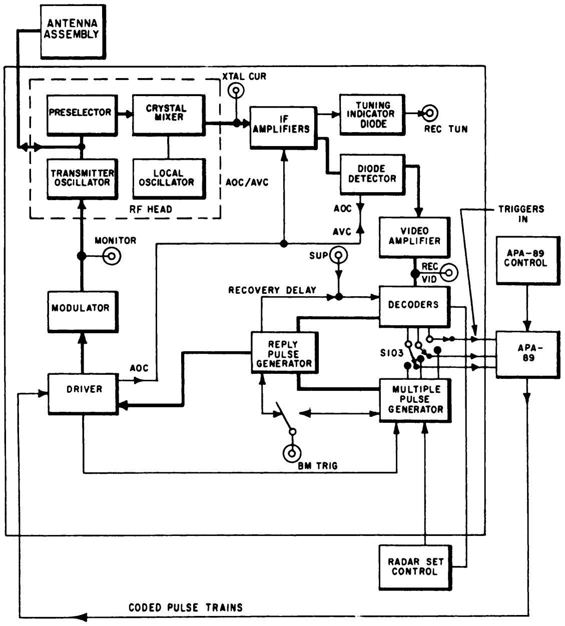


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Figure 19-13.—Radar receiver-transmitter.

The main signal channel is automatically blocked at the decoders for a short, fixed interval (75 to 125 microseconds) following the transmission of each reply pulse or pulse code group. This prevents the transponder from replying more than once to multiple path interrogations, and helps to avoid overloading. External suppression pulses from associated equipment may be injected into the transponder, through the SUP receptacle, to disable all reply transmissions for fixed intervals, during which the associated equipment can operate without interference.

Whenever one of the decoders is triggered into operation, its output is fed into the reply pulse generator, either directly or through the multiple generator, producing a reply pulse or pulse group. The type of reply is governed by the mode of operation for which the transponder is set and the type of interrogation received. In emergency operation, the reply to every type of interrogation is a group of four pulses spaced 16 microseconds apart. The reply pulse generator circuit determines the proper pulse widths. Provisions are made for external triggering of the reply pulse generator through the BM TRIG receptacle. The purpose of this receptacle is to provide a means of triggering the radar receiver-transmitter equipment either as a testing procedure or as a function of an auxiliary equipment.

The reply pulses are amplified in the driver, the output of which drives a modulator employing a dual tetrode, parallel-connected tube. The output voltage of the modulator is stepped up by a modulation transformer. It is then filtered and delivered to the transmitter oscillator in the RF head. A portion of the driver output is fed back to the multiple pulse generator to provide for multiple pulse replies when required, and a portion is used in the development of the AOC voltage.

The transmitter oscillates for the duration of each high-amplitude modulating pulse. The oscillator frequency is determined by the setting of the L.O. FREQ. tuning control on the RF head of the radar unit. A TR tube in the preselector protects the receiver input circuits while the RF energy is generated by the transmitter oscillator and delivered to the antenna.

RF Head

The RF head receives and transmits pulsed ultrahigh-frequency signals. It employs an integral, enclosed RF section, using a lighthouse tube as a transmitter oscillator, another lighthouse tube as a receiver local oscillator, and a crystal diode as a mixer. The tuned circuits consist of singly and doubly reentrant resonant line chambers. The RF head block diagram (fig. 19-14) indicates the main signal path through the RF head.

Front and top views of the RF head mechanical assembly are shown in figure 19-15. The mechanical assembly consists of three vertical cylinders emerging from a rounded, boxlike lower section. The RF head houses a doubly reentrant resonant line and two singly reentrant resonant lines, used respectively by the transmitter oscillator, the preselector, and the local oscillator.

Coupling to and from the RF head is provided by the following:

1. The horizontal cylinder terminating in the antenna receptacle J401.
2. The right-angle cylinder, which houses the crystal mixer and filters and terminates in the mixer output connector J404.
3. A receptacle (J401) in the transmitter oscillator anode chamber, into which modulation pulses are injected through a cable terminated by connector P411.
4. A feed-through type capacitor (C403) located on the local oscillator chamber, through which the local oscillator plate voltage supply is fed.
5. A 9-pin connector (J454) to which plate and filament voltages are fed.

Special Circuits

TUNING MECHANISM.–The tuning mechanism controls the resonant frequency of the reentrant lines. Three knurled, disk type controls identified as TRANS-FREQ., L.O. FREQ., and RCVR-FREQ. are mechanically linked to pistons which control the frequency of the transmitter, local oscillator, and receiver RF section, respectively. These controls are shown in figure 19-15.

When any one of the controls is turned, its associated piston is raised or lowered in the resonant line. This causes the resonant frequency of the line to change; the direction of change depends on the direction in which the control is rotated. If dial rotation is in such a direction as to cause maximum piston insertion, the lowest frequency is obtained. Maximum rotation of the dial in the opposite direction then causes the piston to be withdrawn from the line and increases the frequency.

For convenience in making frequency settings, each of the tuning controls has a micrometer scale which ranges numerically from 0 to 3 in steps of 0.01. A calibration chart, furnished with the equipment, lists the proper micrometer settings of the three dials for a particular assigned frequency. The receiver is tunable over

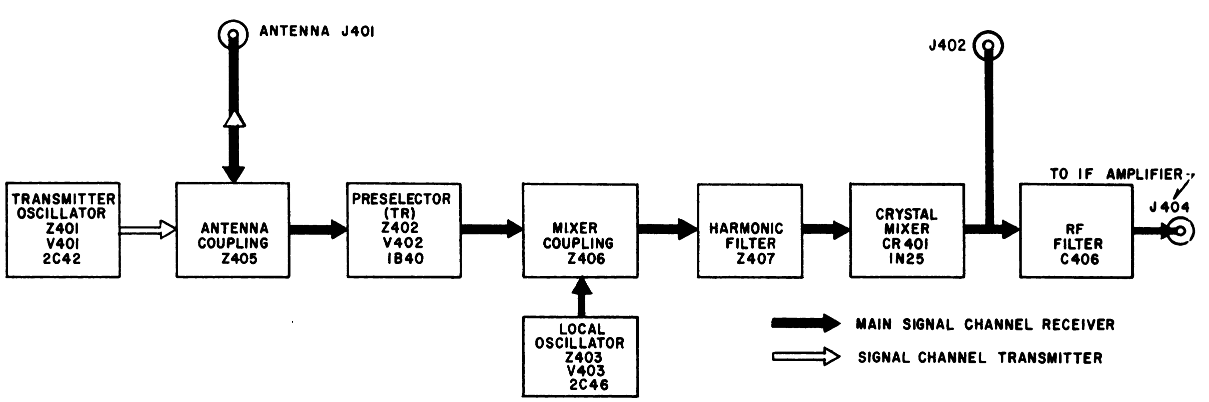
ANTENNA J401
J402
TO IF AMPLIFIER
J404
TRANSMITTER OSCILLATOR Z401 V401 2C42
ANTENNA COUPLING Z405
PRESELECTOR (TR) Z402 V402 1B40
MIXER COUPLING Z406
HARMONIC FILTER Z407
CRYSTAL MIXER CR401 1N25
RF FILTER C406
LOCAL OSCILLATOR Z403 V403 2C46
MAIN SIGNAL CHANNEL RECEIVER
SIGNAL CHANNEL TRANSMITTER

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Figure 19-14.–RF head, block diagram.

a range of 990 to 1,050 megahertz; the transmitter tuning range is 1,070 to 1,130 megahertz.

As shown in figure 19-16, each tuning control has a stationary scale and a movable scale. The stationary scale is graduated from 0 to 3 with scale divisions at 0.25 intervals. The movable scale is graduated from 0 to 25 and makes possible accurate interpolation of the readings of the stationary scale, since a complete revolution of the movable scale equals 0.25, or one division, on the stationary scale.

The movable scale is attached to the knurled dial; therefore, it is rotated by the movement of the knurled dial of the tuning control. Thus to set a tuning control to a particular frequency, determine the correct numerical setting from the

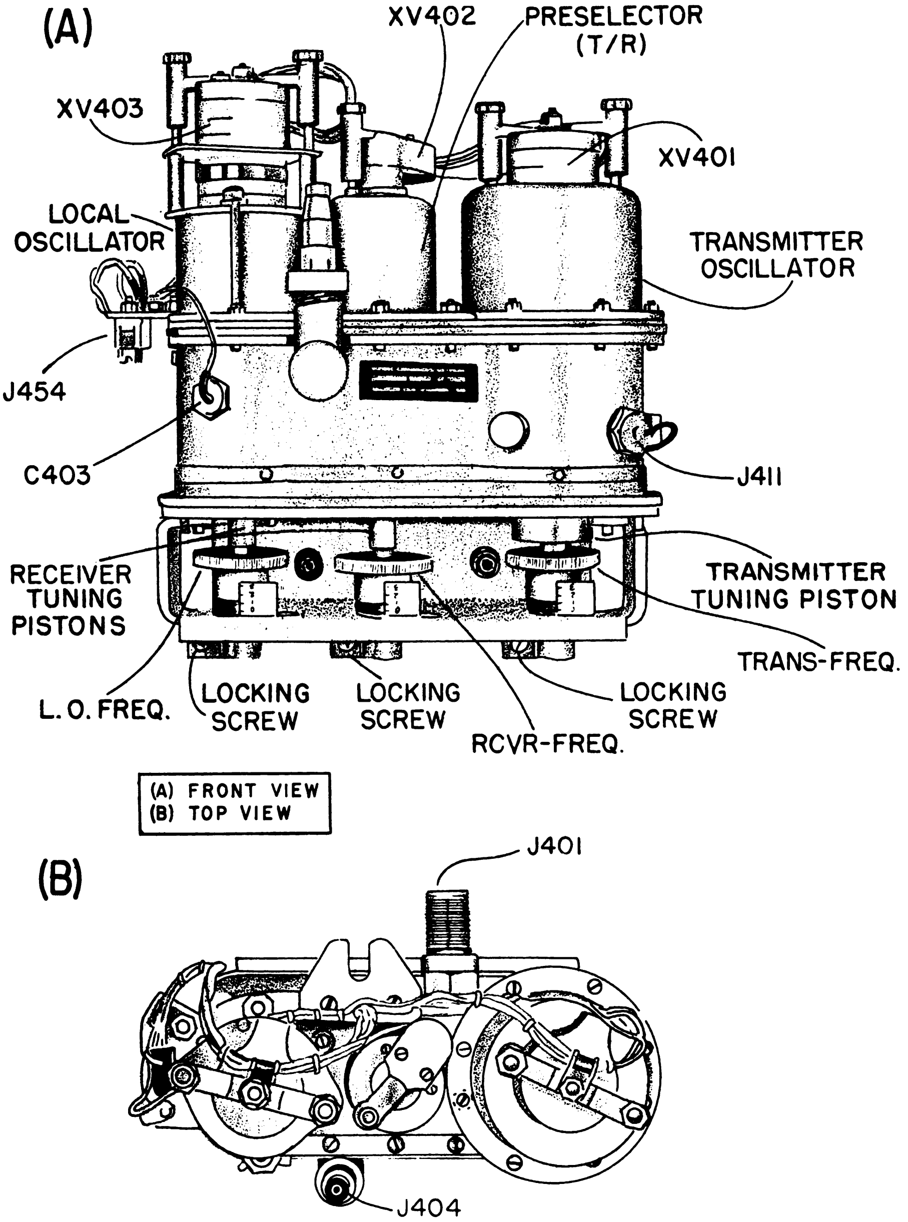

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Figure 19-15.–RF head. (A) Front view; (B) top view.

calibration chart and rotate the dial until the sum of the two scale readings equals that number.

PRESELECTOR.–As shown in figure 19-14, the preselector is located between the transmitter oscillator and the local oscillator, sharing with the former a common coupling to antenna receptacle J401, and sharing with the latter a common coupling to the mixer. Received signals enter the preselector through J401, and then are transferred to the mixer (together with the CW output of the local oscillator).

Functionally, the preselector is an open circuit, single reentrant, half-wave resonant line, capacitively loaded by a type 1B40 gas switching tube V402. This tube is inserted in the top of the chamber, and its envelope is held between two narrowly spaced contact rings that form the TR gap. During transmission, some of the RF energy generated in the transmitter-oscillator chamber enters the preselector, causing the gas to ionize. This prevents transmitter energy from entering the main signal channel of the receiver. During reception, the TR tube is substantially deionized (although a keep-alive voltage is applied across its electrodes to maintain the gas in a state of partial ionization). Since the energy level of received signals is too low to ionize the tube, the preselector acts as a tuned circuit for the crystal mixer, thus providing a maximum transfer of RF energy from the antenna line to the mixer.

LOCAL OSCILLATOR.–As shown in figure 19-15, the local oscillator chamber is located at one end of the RF head. Energy from its single reentrant line is delivered to the mixer through an iris and the mixer coupling Z406. The oscillator is a type 2C46 lighthouse tube, the output of which is set 59.5 megahertz above the frequency of received signals. The local oscillator circuit is unconventional because it makes use of a factor that normally would disable a single tuned oscillator–a considerable transit time between plate and grid. In a conventional low-frequency oscillator, where transit time is negligible, the grid and plate of the oscillator tube are connected to opposite ends of the tank circuit, as shown in figure 19-17. The phase of the plate-to-grid feedback voltage is shifted 180° to aid the grid input voltage and to produce oscillations in the tank circuit. However, in the present circuit, transit time causes a phase shift of

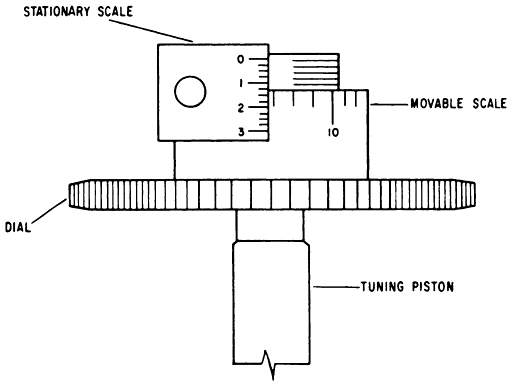

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Figure 19-16.–Tuning control.

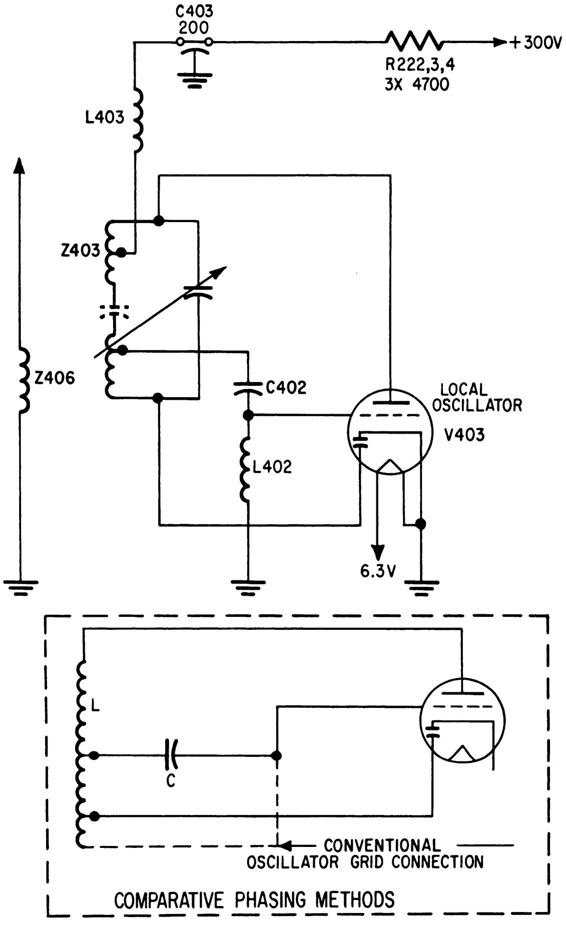

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Figure 19-17.–Local oscillator, equivalent circuit.

180° between current leaving the cathode and current entering the plate; and this, for instantaneous values, causes grid and plate voltages to be in phase. This condition would prevent oscillation in a conventional oscillator circuit but, when modified as in the present circuit, produces satisfactory oscillation. This is done by reversing the grid and cathode connections to the tank circuit. The plate and cathode are connected to opposite ends of the tank circuit, and the grid voltage is tapped off at the point on the line that provides feedback voltage of suitable amplitude and phase angle to sustain oscillations.

The local oscillator circuit (fig.19-17) may be considered as a UHF variant of the Colpitts circuit. Capacitance C402 and inductance L402 form a voltage divider that establishes the proper grid potential. Separate RF and d-c cathode ground connections are utilized to isolate any self-inductance in the d-c cathode circuit. Supply choke L403 consists of a portion of the B-plus lead, which is long enough to produce a pronounced inductive reactance at the frequencies involved.

HARMONIC FILTER.–A harmonic low-pass filter (Z407, fig. 19-14) is inserted into the main signal channel between the mixer coupling (Z406), and the crystal mixer (CR401) in order to bypass undesired signals from other equipments operating nearby in the frequency ranges which might interfere with proper transponder operation. The filter consists of a concentric line, short-circuited at the input end, which is less than one-quarter wavelength for the third harmonic frequency (3,090 MHz). The line is supported at the output ends by a ceramic ring. The entire filter is enclosed by a grounded metal shell, which forms a double capacitor with the inner and outer conductors of the concentric line.

CRYSTAL MIXER.–After passing through harmonic filter Z407, the combined outputs of the preselector and the local oscillator are applied to the cathode contact of the silicon crystal diode, CR401. The crystal is mounted so that it minimizes shunt capacitance, while providing an easy means of removal and replacement.

The output of the crystal mixer includes the original carrier frequency, the local oscillator frequency, and combination frequencies of which the difference frequency (59.5 MHz) is the desired intermediate frequency. The IF input circuit is resonant at 59.5 megahertz; therefore, the difference frequency of 59.5 megahertz is fed with a minimum attenuation to the IF amplifiers. Capacitor C406 functions as an RF filter capacitor to bypass the undesired higher frequencies to ground. This capacitor offers 10 ohms (approximately) of capacitive reactance to 1,000-megahertz signals, and still less to higher frequency signals. The crystal current can be measured at the XTAL CUR receptacle; crystal-current measurement serves as a convenient check on the operation of the local oscillator and the crystal mixer.

SIF AUXILIARY CODER AND DECODER

The Selective Identification Feature (SIF) for IFF Mark X was developed for the purpose of expanding the utility of the MARK X system by increasing its flexibility through a multiple-code transponder reply technique.

By such means, selective and individual identification of aircraft is entirely practicable, facilitating ground control of friendly aircraft, providing operational flexibility associated with the identification process, and thereby incurring a measure of additional security in use of the Mark X system.

The Mark X aircraft transponders have the capability of operation with an auxiliary coder group. This coder is not to be confused with the BLACK MARIA. Coder Group AN/APA-89 is the principal airborne component required to equip IFF Mark X with the selective identification feature. Video Coder KY-81/APA-89 comprises the electronically operated portion of the AN/APA-89.

When Coder Group AN/APA-89 is employed with the transponder, normal transponder operation is modified considerably by S103 (fig. 19-13), the NORM-MOD switch. When Video Coder KY-81/APA-89 is being used with the transponder, S103 is placed in the MOD position. In the MOD position none of the multiple-reply or single-reply pulse circuits between the decoders and driver V110 are used. Instead, the reply pulses, in the form of pulse trains, are generated in Video Coder KY-81/APA-89 and injected at the grids of driver V110. Since the transmitter circuitry has not been altered, transmission of the coded pulse trains occurs in the same manner as if normal replies were being transmitted.

For normal operation without the use of an auxiliary coder, S103 is placed in the NORM position.

THEORY OF OPERATION OF CODER

The output of the receiver portion of an aircraft transponder when used with the AN/APA-89 consists of single, positive pulses of an amplitude of approximately 7 volts and a duration of 1 microsecond in any one of the three modes. The mode of the interrogating signal received by the associated transponder determines whether the input pulse appears in mode 1, mode 2, or mode 3, since the output from the transponder is used to trigger one of the gate generators (See fig. 19-18 for remainder of coder discussion.)

Each of the gate generators is a one-shot multivibrator. In each, the output is a positive gate pulse whose width (between 35 and 55 microseconds) is determined by circuit parameters. The output of the gate generator (only one is operative at any one time) is applied to the common delay-line driver, and to a corresponding crystal-coincidence circuit.

The delay-line driver operates as a blocking oscillator, generating a pulse approximately 1.35 microseconds wide for each gate pulse it receives.

The 1.35-microsecond pulse is applied to the delay line to establish the pulse train. It is also applied to the pulsed sine-wave oscillator for synchronization.

The delay line is tapped at fixed intervals. The pulse output from each tap may be selected by individual switches, through equalizing resistors and crystal-diode isolating elements, for feeding to a common collector bus.

Three distinct common collector buses are used in the equipment, one for each mode. Separate sets of mechanical or electronic switches are provided so that only those pulses which are desired for a pulse train appear on the collector buses. Therefore, the outputs on each mode collector bus consist of trains of pulses, spaced at fixed intervals, as selected by the mode-selector (mechanical or video) switches.

In order to select and transmit the proper mode coding, three crystal-coincidence circuits are used, one for each mode. Each of these circuits has two input terminals. Each circuit will conduct only when the proper input signals are applied simultaneously to the input terminals. The proper coded pulse train selected for the mode is always fed to one input terminal. Fed to the other input terminal is the signal provided by the gate generator for the mode. Obviously, if either of these two signals is absent, no output will be derived from the circuit. Conversely, if both signals are applied simultaneously, an output will appear, but only for the length of time during which the circuit is gated to the on condition by the gate-generator pulse.

The output of the crystal-coincidence circuit consists of a train of pulses substantially equal in amplitude and spacing to that appearing on the mode-collector bus of the mode-collector switches. Further, since the design of the transponder prevents triggering of more than one gate generator at a time, no gate pulses appear at the input of the remaining two crystal-coincidence circuits. For this latter reason, the remaining two crystal-coincidence circuits are not gated to the on condition, and the output signal appearing on the common coincidence bus consists only of the coded pulse train of the mode in use.

Accurate spacing of the pulses in the train is of prime importance. This accuracy is achieved by utilizing the signal from a pulsed sine-wave oscillator to control the spacing. This oscillator, generating a signal whose frequency corresponds to the pulse-to-pulse spacing of delay-line taps, is started by the same pulse which drives the delay line. The oscillator signal is coupled to the second control grid of the coincidence mixer.

The function of the coincidence mixer is to provide an electrical location where the pulses from the delay line, constituting the coded pulse train, may be mixed by being superimposed upon the positive peaks of the signal from the pulsed sine-wave oscillator. Electrically, the pulses derived from the delay line and applied to the first control grid of the coincidence mixer act as gates which allow the tube to conduct. As a result of this conduction, the output of the coincidence mixer consists of pulse-train signals substantially the same as those from the crystal-coincidence circuits but with one significiant exception. Whereas the pulses appearing at the output of the crystal-coincidence circuits have

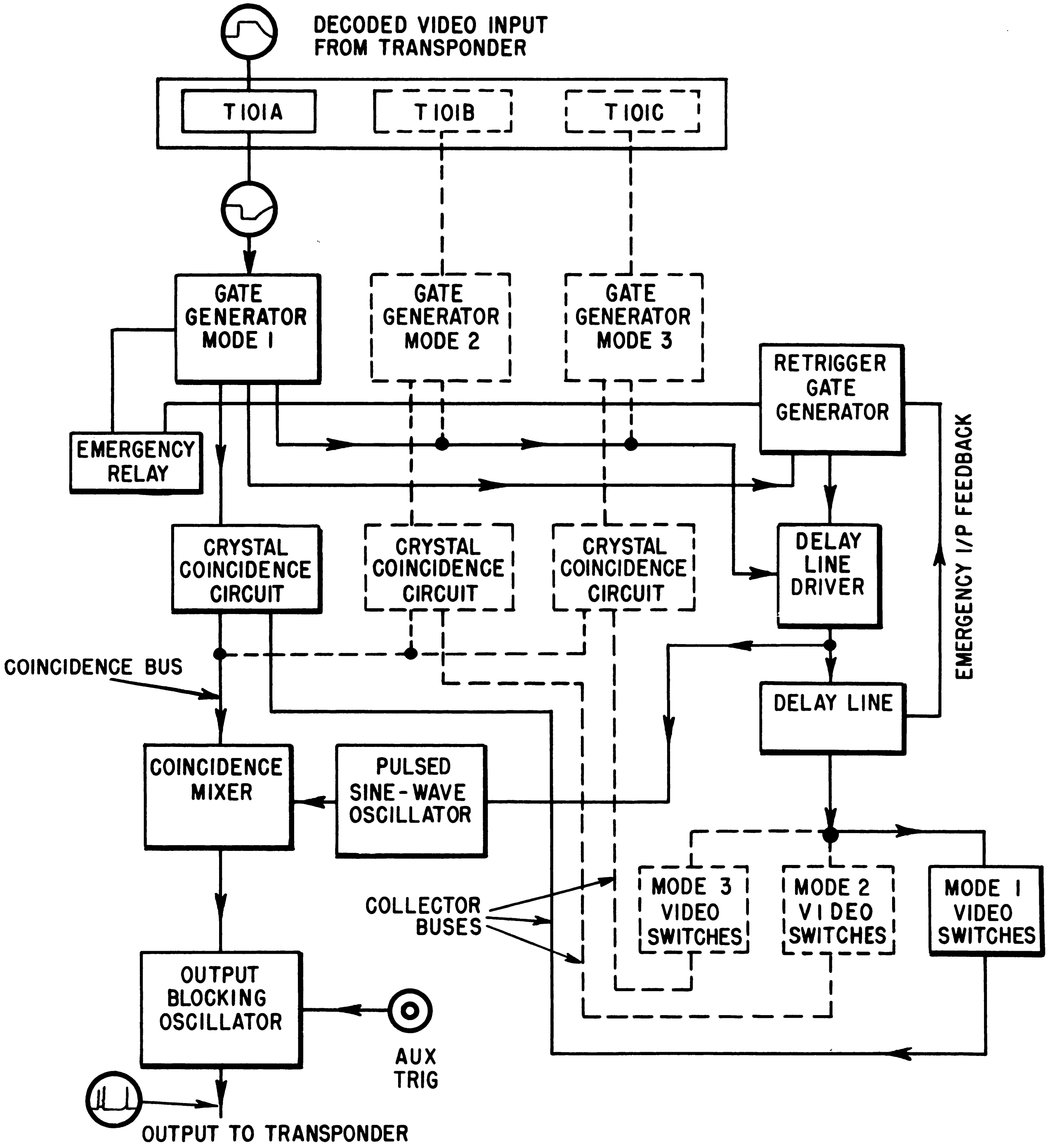

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Figure 19-18.—SIF, block diagram.

spacings determined by the accuracy of the delay-line configuration, those pulses appearing at the output of the coincidence mixer have time-controlled spacings determined by the frequency of the pulsed sine-wave oscillator.

The pulse train from the coincidence mixer is applied to the output blocking oscillator. In the process, a ringing circuit is used to shape the individual pulses. The output blocking oscillator generates a train of pulses at a high amplitude across an impedance of 90 ohms for application to the transmitter portion of the transponder.

Pilot Identification (I/P)

Pilot Identification or I/P is accomplished by utilizing a retrigger gate generator operated by the output of the mode 1 gate generator and the "Emergency-I/P Feedback" pulse from the delay line to produce an extra pulse train. Until the I/P feature is desired, the retrigger gate generator is quiescent. When the I/P switch is closed, however, the following takes place: (1) the grid of the first half of the retrigger gate generator is raised to ground potential from its normal below-cutoff level, and (2) the leading edge of the differentiated mode 1 gate-generator pulse applied to this grid initiates multivibrator action. A rectangular pulse is thus produced which corresponds in width to that from the mode 1 gate generator.

The positive pulse generated by the retrigger gate generator is coupled to the anode terminal of a crystal diode inserted in the "Emergency-I/P Feedback" bus. If no pulse from the delay line exists on this bus, the retrigger gate-generator output is effectively shorted to ground by the low impedance presented by the delay-line terminating resistor. If, however, a pulse from the delay line appears on the "Emergency-I/P Feedback" bus, the crystal diode is cut off and the retrigger pulse from the delay line is coupled to the input grid of the line driver. When this pulse appears, the line driver retriggers and an extra train on pulses is generated.

This generation of additional pulse trains in groups of two continues for the length of time the I/P switch is held closed and for approximately 30 seconds after it is opened, provided that incoming trigger pulses actuate the mode 1 gate generator. The 30-second continuation of pulse trains is accomplished by a resistor-capacitor network in the bias circuit of the retrigger gate generator. This network is completely discharged by the closing of the I/P switch. When the switch is opened, the resistor-capacitor combination is allowed to charge from the bias supply. When the combination has charged sufficiently (in about 30 seconds), the retrigger gate generator is cut off and the tube reverts to its quiescent condition.

Emergency

The emergency feature makes use of the same circuitry as does the I/P feature. In addition, however, a relay is provided and is actuated by the closing of the emergency switch on the transponder set control. One set of contacts on this relay is used to connect additional capacitance in the grid circuit of the mode 1 gate generator, approximately doubling the width of the pulse produced by this multivibrator. Another set of contacts shorts to ground the grid return of the retrigger gate generator.

When the relay is energized, the following events take place: (1) upon receipt of an incoming mode 1 trigger, the mode 1 gate generator produces a gate pulse approximately 110 microseconds wide, and (2) the retrigger gate generator performs as it did during I/P operation, producing a positive rectangular pulse approximately the same width as that of the mode 1 gate generator. Again the line driver is retriggered as it was in I/P operation. During emergency operation, however, the number of output pulse trains is increased to four for each mode 1 incoming trigger pulse. When the emergency relay is deenergized, the system reverts to normal and the retrigger gate generator is again quiescent.

Pulse Train Coding

The coding of each mode is accomplished by the use of the octal code. (Reference may be made to chapter 15 of this manual.) Up to three bits are used for each number. This means that we may select a number of 0, 1, 2, 3, 4, 5, 6, or 7 by use of a maximum of three octal bits. For a number such as 37 (eight) two groups of bits in octal form are necessary. They would be 011 octal to obtain the 3 and 111 octal to obtain the 7. Now consider the grouping for the 3 as group "A" and the grouping for the 7 as "B." Therefore, for a four digit number the grouping from LEFT to RIGHT would be A, B, C, and D. It must be understood at this point that there will be no more than three pulses created to represent each coded number group. To create a 77, six pulses are necessary.

The code structure created by the APA-89 is established on a 20.3-microsecond time base as measured between the leading edges of the "start bracket" pulse and the "stop bracket" pulse. (See fig. 19-19.) The information pulse positions are shown in the composite code train and are used for the pulse coding. Twelve pulse positions are necessary to represent four octal coded numbers. The twelve pulse positions are divided into four equal groups and are designated A, B, C, and D.

Group A and group B pulse positions are used for reply codes in mode 1, mode 2 (6-pulse), and mode 3. Therefore, two octal numbers are assigned. Four-place octal numbers can be assigned to mode 2 (12-pulse) codes.

In mode 1 there are 31 code structures (01 to 73). Mode 2 (6-pulse or two numbers) and mode 3 have 64 code structures (00 to 77).

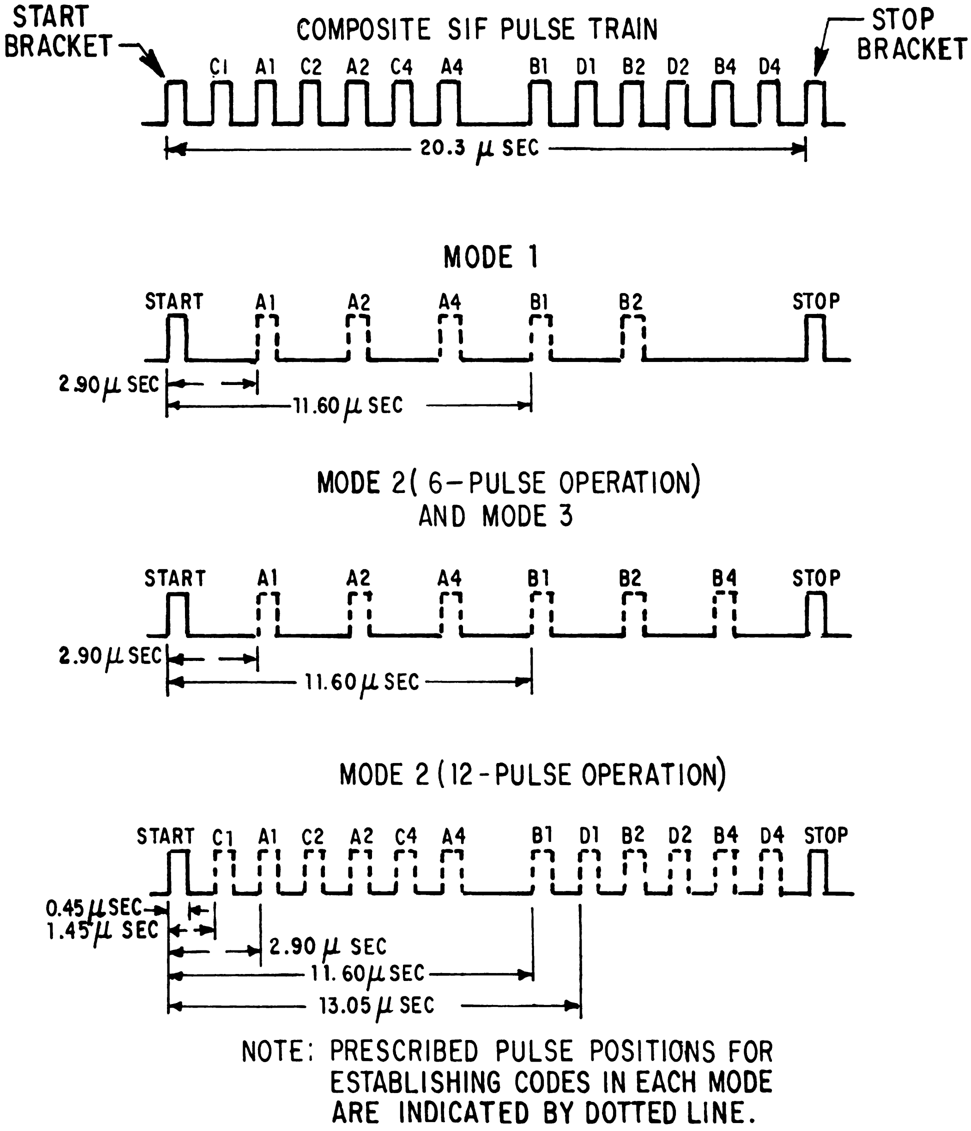
START BRACKET
COMPOSITE SIF PULSE TRAIN
STOP BRACKET
C1 A1 C2 A2 C4 A4 B1 D1 B2 D2 B4 D4
20.3 μ SEC
MODE 1
START A1 A2 A4 B1 B2 STOP
2.90 μ SEC
11.60 μ SEC
MODE 2 (6-PULSE OPERATION) AND MODE 3
START A1 A2 A4 B1 B2 B4 STOP
2.90 μ SEC
11.60 μ SEC
MODE 2 (12-PULSE OPERATION)
START C1 A1 C2 A2 C4 A4 B1 D1 B2 D2 B4 D4 STOP
0.45 μ SEC
1.45 μ SEC
2.90 μ SEC
11.60 μ SEC
13.05 μ SEC
NOTE: PRESCRIBED PULSE POSITIONS FOR ESTABLISHING CODES IN EACH MODE ARE INDICATED BY DOTTED LINE.

Figure 19-19.—IFF-SIF reply code structure. AT.375

Mode 2 may be assigned four numbers (0000-7777). In this case, it would have to use all 12 pulse positions and there would be 4096 possible code structures.

To code a reply of 35 (octal) requires that a pulse be present at the prescribed position for start pulse, A1, A2, B1, B4, and stop pulse and that no other pulses be present at the other prescribed positions of the code train. A mode 2 (12-pulse) code of 7264 would have pulses of start pulse, A1, A2, A4, B2, C2, C4, D4, and the stop pulse.

THEORY OF OPERATION OF DECODER

The KY-364/APX Video Decoder is a compact, transistorized instrument incorporating all functional controls and decoding circuitry within a single unit. It provides SIF decoding capability in an airborne radar recognition facility of the IFF Mark X (SIF) system. The purpose of the KY-364/APX unit is to accept mode-separated (SIF) IFF video pulses, process them, and supply decoded output pulses for display as the IFF target on an associated PPI scope. (See fig. 19-20.)

Figure 19-1 shows an overall airborne IFF system without the SIF feature. The specific equipment discussed is used as a teaching vehicle. Although there are many adaptations and later equipment, basically the theory of operation is the same.

Upon receiving a signal resulting from interrogation, the video decoder of the APX-7 supplies output signals for use in conjunction with the associated KY-364 decoder. (See fig. 19-20.) The information pulses of each reply code train are provided by the KY-84 coder synchronizer. A bracket coincident gate is also furnished for the KY-364 decoder.

The code train input is applied to a multiple-tapped delay line and is processed by logic circuits to derive a PASSIVE DECODE signal and a BRACKET DECODE signal. A provision is made to bypass the logic circuits and generate the CODE video output. The video pulse outputs of the decoder are applied to the azimuth-range indicator (PPI type) and are displayed as the IFF target. For each reply-code received from a challenged aircraft, two logical operations are available and, depending on the reply code structure, two discrete signals are generated. The CODE video output is always available since it is not processed through the logic circuits. One of the three outputs, PASSIVE DECODER, BRACKET DECODE, or CODE video, is selected for PPI display by a front panel switch (fig. 19-21).

Passive Decode

The passive decode function is a check for equality between the reply code train and the preset code of the video decoder. If the reply code is equivalent to the preset code, a single decode pulse is generated. (See fig. 19-22 (A).) If it is not equivalent, a decode pulse is not generated. An acceptable code for each of the three operating modes is set individually and can be changed readily by means of code select switches on the front panel. (See fig. 19-21.)

Bracket Decode

The bracket decode function is a check for coincidence of the start and stop pulses that frame an SIF reply code train at precisely 20.3 microsecond duration. A single bracket output is generated (fig. 19-22 (B)) if these two pulses are present. The bracket start and stop pulses are required in any SIF reply code train. Consequently, when selected, the bracket decode output displays responses from all SIF-equipped targets regardless of reply-code and preset-code equality.

Delay Code Video

After the DELAY CODE VIDEO bypasses the logic circuits, it is delayed 40.8 microseconds from the time of input. In the DELAY CODE position, both the SIF pulse coded trains and the basic (non-SIF) IFF reply pulses from all challenged targets are displayed. (See fig. 19-22 (C).)

Additional Features

A degarble feature incorporated in the video decoder is controlled by a front panel switch. When activated, the degarble circuits detect the presence of reply code train interference and prevent decode outputs of garbled pulse trains. This feature partially reduces the occurrence of false IFF target displays. Garble interference is

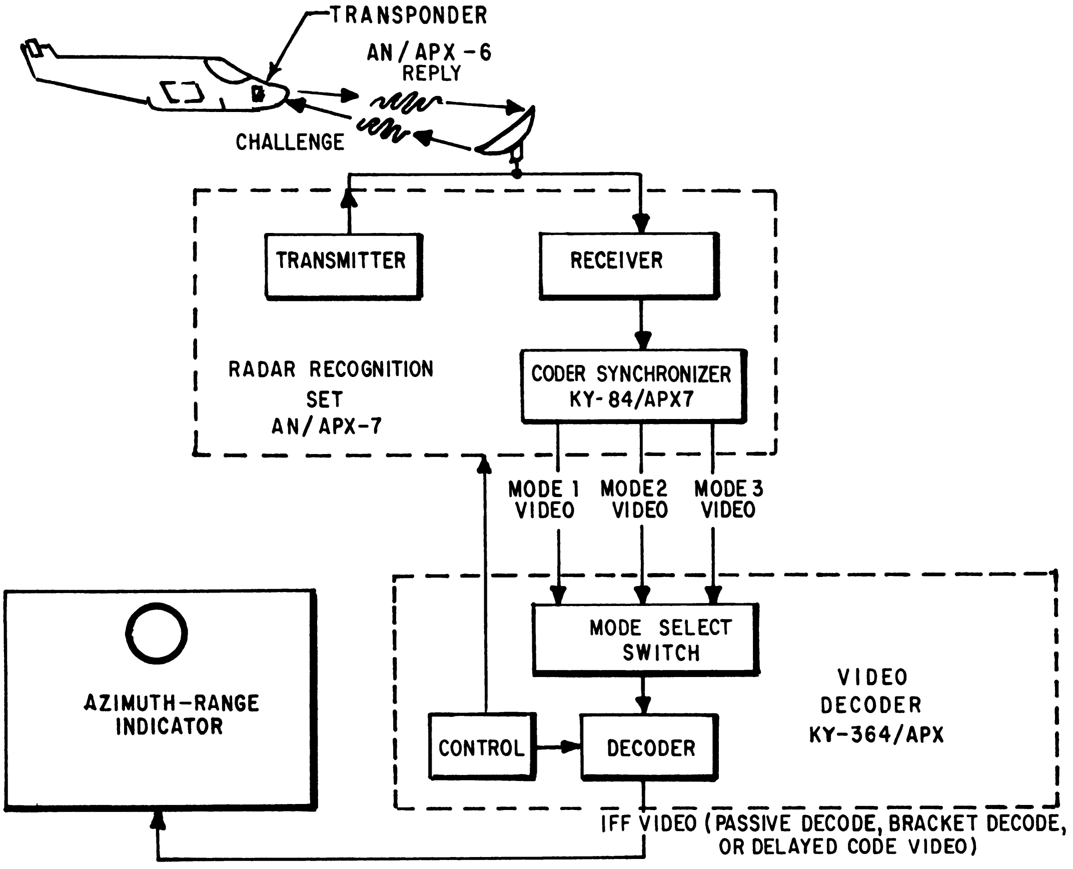

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Figure 19-20.–Airborne Radar Recognition System, block diagram.

created under various and random conditions. The replies of two or more challenged targets at approximately the same range and bearing may be garbled. Multipath reception from a single target may result in a garbled reply; and, in areas of high-density traffic (around large airports), nonsynchronous replies will often cause replies to be garbled. The video decoder has the capability to individually decode four interleaved 6-pulse code trains, or two interleaved 12-pulse code trains. The accurate decode tolerances of the video decoder significantly increases reliability for resolving interleaved replies and rejecting garbled replies.

Selective Identification

Utilization of the selective identification feature (fig. 19-21) may be accomplished as follows:

With the OUTPUT switch in the BRACKET or CODE position, all SIF target replies for the set mode of challenge are displayed on the PPI. Then, by setting the MODE 1 CODE, MODE 2 CODE, or MODE 3 CODE switches to the preassigned code and by placing the OUTPUT switch in DECODE position, a specific target, or group of targets, whose reply-code is equivalent to the preset code is displayed. The MODE SELECT switch may be rotated through its three positions to monitor on the PPI scope each mode of operation. This may be accomplished by sector scanning or on successive antenna revolutions.

Indicator Presentations

A typical PPI display is shown in figure 19-22 for each selectable output of the video

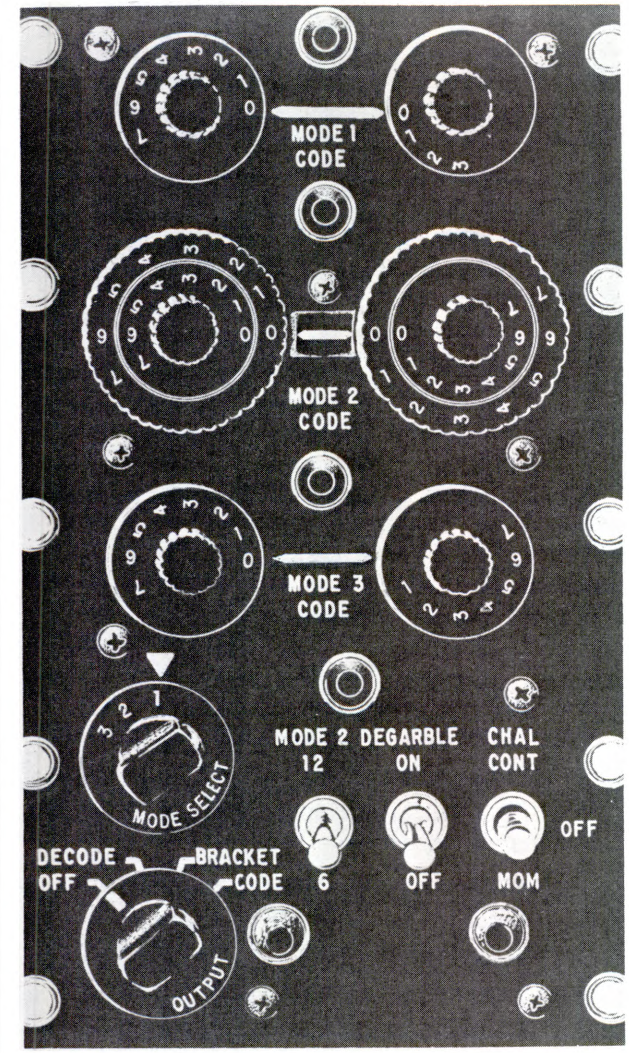

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Figure 19-21.–Video Decoder KY-364/APX.

decoder. These displays show IFF responses. If radar targets are also displayed, the IFF response appears at a greater range than the radar target because of the preset delay in the IFF equipment.

BENCH TEST AND ALINEMENT

For specific procedures for testing and alinement of specific equipment, refer to the appropriate equipment manual.

The purpose of this section is to discuss various pieces of shop test equipment that are used with the IFF Mark X equipment in general.

AN/UPM-4

One of the earliest pieces of shop test equipment was the AN/UPM-4. This equipment was capable of testing the earlier APX-equipment; but with the advent of the SIF, this equipment became obsolete.

AN/UPM-70

The AN/UPM-70 superseded the AN/UPM-4. It provides complete facilities for performing corrective maintenance on operational (and some test) equipment in the IFF Mark X system. This test set consists of two basic units, an oscilloscope and a coder simulator. It could also be used for making some of the more common tests required for maintenance of radar equipments operating in the 925 to 1225 megahertz frequency range.

The following list briefly outlines the tests that can be performed with the Radar Test Set AN/UPM-70:

1. Measurement of RF power.
2. Measurement of RF frequency.
3. Investigation of RF pulse characteristics.
4. Equipment analysis using simulated IFF Mark X codes, both the basic modes and the SIF codes.
5. Measurement of receiver bandwidth, frequency, and sensitivity.
6. Measurement of PRF.
7. Video pulse analysis.
8. Signal tracing.

AN/UPM-98

The AN/UPM-98 is a single unit test set that has an advantage in the ability to make rapid checks.

It performs the following checks on a transponder and SIF codes.

1. Receiver rapid check of sensitivity and tuning.
2. Transmitter rapid check of power output, tuning, frequency, SIF coding, and emergency and I/P function.
3. SIF coding check.
4. Mark X Coding check (non-SIF).

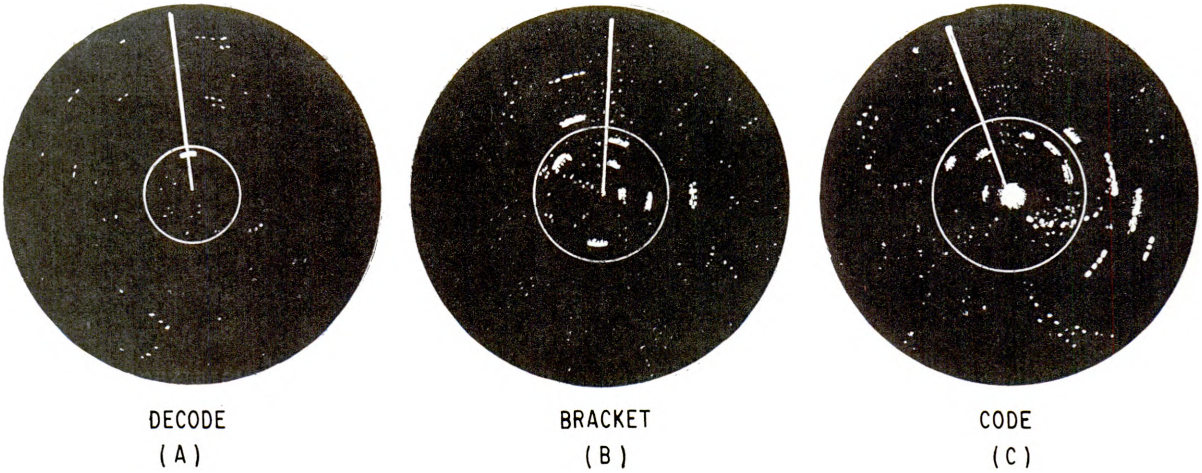

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Figure 19-22.–Typical PPI displays.

5. Automatic overload circuit check.
6. Recovery and suppression check.
7. Bandwidth and tuning indicator check.

On the interrogator-responses (IR) unit it will check the following:

1. Count down circuits.
2. Triple gate generator.
3. Coder pulse pair spacing and width.
4. Coded IF pulses.
5. Transmitter frequency.
6. Transmitter power and pulse shape.
7. Receiver sensitivity, frequency, and video output.
8. Suppression adjustment.
9. Receiver gate adjustment.

AN/UPM-99

The AN/UPM-99 Radar Test Set is basically an AN/UPM-4A with a new display unit attached. Individual checks and adjustments may be performed without the necessity of performing the entire procedure.

This test set will perform any check that the AN/UPM-98 can perform.

CHAPTER 20

ELECTRONIC COUNTERMEASURES

It is the purpose of this chapter to introduce the general principles involved in the operation of electronic countermeasures devices. In the discussion which follows, examples of countermeasures equipments are described to illustrate these principles. The descriptions of the units included here are not intended to provide detailed information concerning maintenance and operation, but are given solely to present the broad basic facts which are common to many examples of countermeasures equipments, both old and new.

It is a basic rule of warfare that for each weapon used by the enemy a counterweapon must be developed. This rule is clearly expressed in modern war by the development and use of electronic countermeasures (ECM). The counterweapon in this case is used against enemy electronic equipment—against radar, communication transmitters and receivers, navigation aids, and electronically controlled weapons (such as guided missiles and proximity fuses). The objective of ECM is to make the enemy's use of these electronic devices ineffective.

SIGNAL CHARACTERISTICS

To prepare effective countermeasures against communication systems and navigation aids, information is needed concerning the frequencies of the emissions, the types of modulation used, the polarization of the transmitted waves, and the exact locations of the stations. For countermeasures against enemy radar, much more information is required. The principal signal characteristics of importance are the carrier frequency, the pulse repetition frequency, and the pulse width. In addition, other data are very desirable. These include the type of scan employed, the rate of scan, the beam width, and the polarization of the antenna.

CARRIER FREQUENCY

The carrier frequency of the enemy radar is the starting point from which the other signal characteristics are determined. Knowledge of the frequency is necessary for determining the type of the radar and its probable function and for preparing effective jamming operation.

PULSE REPETITION FREQUENCY

The second most distinguishing characteristic of the radar is its pulse repetition frequency (PRF), which is the number of pulses emitted per second. The PRF value is a factor in determining the maximum range of the unit since it governs the time interval between the pulses. Long range air search radars must necessarily use low PRF values, since the pulses need to be spaced at intervals sufficient to allow echo signals to return from the most distant object within the desired range. Higher values of PRF are used in surface-search radars designed for detecting objects at shorter ranges. Extremely high pulse rates are employed in such equipment as fire control radars, which have very short range but extreme accuracy.

PULSE WIDTH

It is desirable to know the pulse width of radar signals since this value is the basis for estimating the minimum range of the unit. Pulse width is the interval of time during which the radar transmitter is energized; as a result, it determines the minimum range at which target echoes can be received.

TYPE AND RATE OF SCAN

The type of scan, the method by which the radar beam searches the target area, is a good indication of the nature and action of the radar. Types of scan include 360-degree, sector, lobe-switching, conical, and spiral scans. The simplest way of distinguishing the scan type is by listening to the intercepted signals. Signals from search radars usually cause a whine in the headphones, the tone being produced by the constant pulse rate. In a 360-degree scan, the signal strength varies periodically as the beam sweeps over the search aircraft. As long as the signal variations continue, the radar is searching; but if the sound becomes loud and steady, the indication is that the set has probably detected the search aircraft and is concentrating its attention on it. Fire control radars often use lobe switching in which the beam locks first to one side of the target and then to the other side. The shifting of the beam takes place rapidly and brackets the target while the radar compares the echoes from each beam position. Lobe switching is easily detected by visual indications of the signals on panoramic adapters, pulse analyzers, and direction finders. It also causes a characteristic chatter in the headphones as the beam position varies.

The rate of scan, or number of scanning sweeps made per minute, is related to the probable maximum range of the radar. Slow scanning is characteristic of long-range search sets, while short-range radars and fire control systems employ much higher scan rates. The rate is usually measured in terms of the time required for one scan. The signals are observed on the screen of a panoramic adapter or the scope of a direction finder. The operator logs the time interval between successive indications of maximum signal strength.

BEAM WIDTH AND POLARIZATION

The measure of the beam width gives an indication of the azimuth accuracy of the enemy set. The width of the beam, which is expressed by the number of degrees between the half-power points, is generally computed from data provided by automatic recorders which give information concerning the amplitude of the signals.

The polarization of the radar antenna is considered in planning effective methods of jamming. This characteristic can be determined by use of direction finders of the type which makes a visual display of the reception. The direction finder is equipped with two antennas—one polarized horizontally and the other vertically. Either antenna can be used for reception, and the polarization of the incoming signals is learned by comparing the patterns resulting from each.

A rough determination of polarization can be made by alternate shifting from vertical to horizontal receiving antennas. The antenna which is of proper polarization for the signal being received will provide an audible response indicating greater signal strength. Circular polarization will give approximately a uniform response on either antenna.

PASSIVE ECM

Passive ECM operations are those which cannot be directly detected by the enemy; examples include reconnaissance and search operations, in which enemy transmitters are detected and located and as many as possible of the signal characteristics are determined. Passive countermeasures also include evasive tactics taken to avoid detection, and methods of controlling the radiations from friendly equipments to prevent the enemy from using our signals for homing, direction finding, or for any other purpose.

SEARCH RECEIVERS

The success or failure of an intercept mission depends largely on the proper functioning of the search receiver, the basic type of passive countermeasures equipment. By means of the receiver, the ECM operator detects the presence of radar and radio emissions, monitors enemy transmissions, learns the types of modulation used, and records indications of relative signal strength.

Search receivers are designed for intercepting signals occurring throughout wide ranges of frequency. Receivers are usually equipped with several tuning units, each of which can be either manually tuned or automatically swept over a selected frequency sector by motor-driven tuning circuits.

Tape and film recorders are used to make records of the signals received by the associated search receiver as it is tuned rapidly through the spectrum. The recording, which is analyzed after the flight, gives information concerning the frequencies of the signals, the amplitude, and the time of reception.

When searching for enemy radar locations, the ECM receiver operates at a fundamental advantage with respect to the radar. Radar detects objects by reflection, or two-way transmission, in which the reduction of signal strength is proportional to the fourth power of the distance covered by the waves. The receiver, on the other hand, detects the radar by a one-way transmission in which signal reduction is proportional only to the square of the distance. As a result, the presence of the radar can be detected at a distance greater than the maximum range at which the radar can detect the search aircraft.

Receiver Operation

Most search receivers employ superheterodyne circuits that can be tuned rapidly over various bands. The extremely wide frequency coverage required is provided by the use of several tuning units, each of which covers a part of the total tuning range of the receiver. Tuning units usually consist of a tuned antenna circuit, a local oscillator, and a mixer stage. The receiver produces three types of output—video signal voltages for use in a panoramic adapter, video signals which are applied to a pulse analyzer, and an audio output for the headphones. (A panoramic adapter is a cathode-ray indicator that enables the operator to sweep a broad spectrum of frequencies during a short period of time.) When a signal that the operator desires to inspect closely is displayed on the adapter, it is fed to the pulse analyzer for closer study.

In figure 20-1, a block diagram of a typical ECM superheterodyne receiver system is shown. The receiver covers a wide tuning range by employing several selectable RF tuners.

Signals intercepted by the antenna are fed to a connection on the receiver through a switching assembly. This assembly enables the operator to select the proper antenna for the frequency range to be covered. From the antenna connection, the incoming signals are applied to one of the tuning units.

The tuning unit (fig. 20-2) contains an RF amplifier, a local oscillator, a crystal mixer, an IF amplifier, and a d-c motor which is mechanically coupled to a synchro generator. The motor is also coupled to a counter which indicates the frequency to which the preselector is tuned. The synchro generator transfers frequency information to a cathode-ray indicator unit.

Since there are no manual controls in these tuning units, they are usually remotely mounted to provide better utilization of space in the aircraft. The d-c motor also automatically tunes the RF amplifier and the local oscillator through their frequency range. When the frequency is too high for use with conventional RF amplifier circuits, tunable cavities are incorporated instead. The popular name for these cavities is "RF preselector."

Mixing of the input signal with the signal from the local oscillator, in a crystal mixer, produces an IF frequency. This IF signal is amplified through several stages of preamplification. The preamplifiers are stagger tuned; that is, each stage of preamplification is tuned to a slightly different frequency. This staggered tuning gives a very broad bandpass which is desirable for video work. Impedance matching is used in the output to feed the signal into the next section, a mixer amplifier.

The mixer amplifier (fig. 20-3) contains a main IF amplifier strip, a second IF amplifier strip, and the video and audio circuits of the receiver. It also contains a sweep oscillator, a fixed oscillator, and beat frequency oscillator (BFO). The BFO is a heterodyning oscillator used for detecting CW or MCW transmissions. The sweep oscillator sweeps through a spread of frequencies equal to the receiver bandpass. The sweep oscillator output is mixed with the signal from the main IF amplifier in the mixer stage to produce a new and lower IF frequency. This system of going from one IF to a lower IF is called double conversion and is done to produce a still lower frequency which is easier to amplify. The lower frequency allows the use of simpler circuitry throughout the remainder of

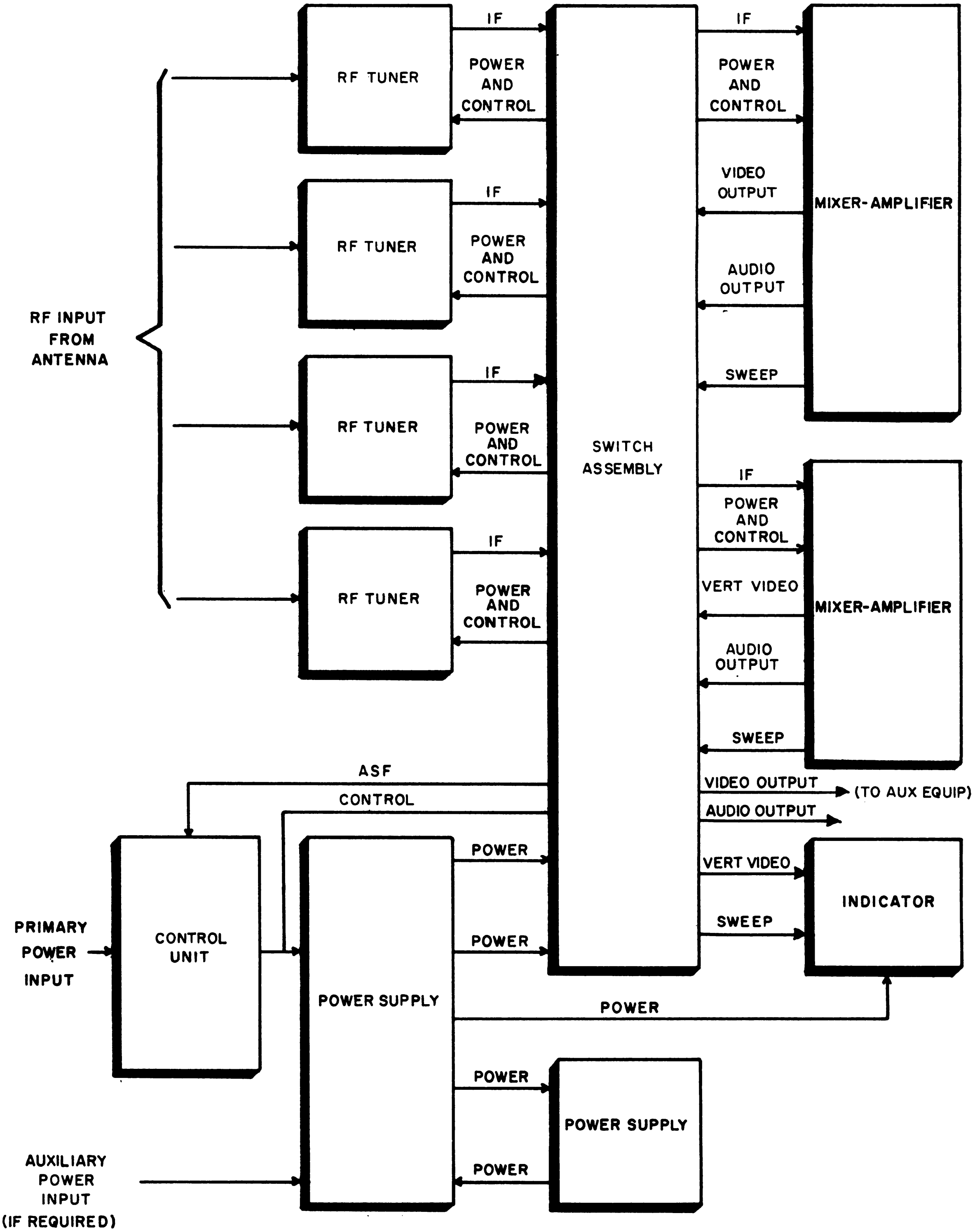

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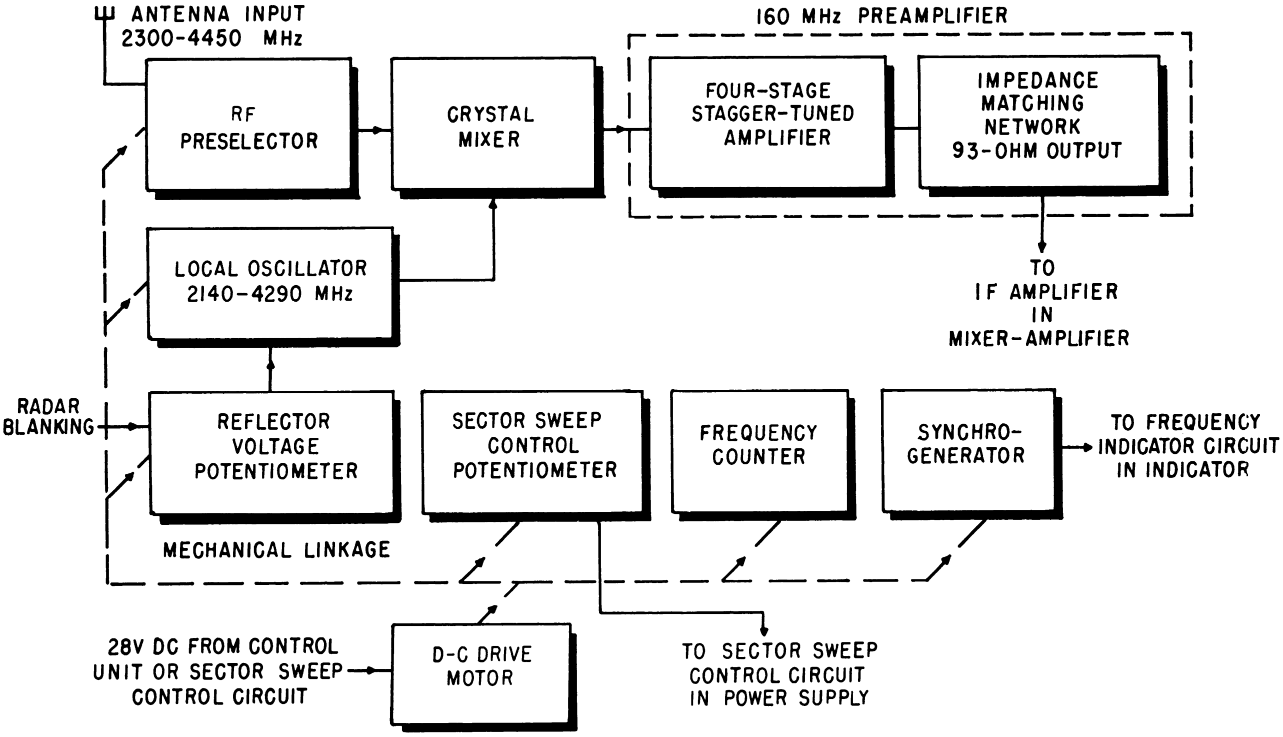
Figure 20-1.—Typical multiple tuner block diagram.


ANTENNA INPUT
2300-4450 MHz
160 MHz PREAMPLIFIER
RF PRESELECTOR
CRYSTAL MIXER
FOUR-STAGE STAGGER-TUNED AMPLIFIER
IMPEDANCE MATCHING NETWORK 93-OHM OUTPUT
LOCAL OSCILLATOR 2140-4290 MHz
TO IF AMPLIFIER IN MIXER-AMPLIFIER
RADAR BLANKING
REFLECTOR VOLTAGE POTENTIOMETER
SECTOR SWEEP CONTROL POTENTIOMETER
FREQUENCY COUNTER
SYNCHRO-GENERATOR
TO FREQUENCY INDICATOR CIRCUIT IN INDICATOR
MECHANICAL LINKAGE
28V DC FROM CONTROL UNIT OR SECTOR SWEEP CONTROL CIRCUIT
D-C DRIVE MOTOR
TO SECTOR SWEEP CONTROL CIRCUIT IN POWER SUPPLY

AT.380

Figure 20-2.—RF tuner block diagram.

the receiver. This second IF signal is fed through several stages of amplification, then to a detector stage. The detector stage produces a video pulse which is available for presentation on the panoramic and pulse analyzer scopes.

During broadband operation the receiver may receive one or more signals simultaneously. In order to view one signal at a time, the receiver is switched to narrowband operation. Since it is mechanically difficult to stop the sweeping oscillator at the exact frequency needed for double IF conversion, a fixed oscillator is provided. The signal from the fixed oscillator is fed into the mixer during narrowband operation.

From the main IF amplifier strip a signal can be detected, amplified, and then made available as a video input for some auxiliary equipment such as a pulse analyzer, a direction finder, or a remote indicator. Provisions are also incorporated so that any signal present will be amplified through an audio circuit to give an audio tone. This tone may be used to aid the operator in detecting signals. He can listen as well as look. This is desirable since eye fatigue is a problem when he must look at the scope continuously.

From the second IF of the mixer amplifier the video signal is fed to the CRT indicator for panoramic or pulse analyzer indication. The signal may also be fed to auxiliary equipment for further pulse analyzing or direction finding.

WAVE TRAPS.—Search receivers of the superheterodyne type often produce spurious responses caused by image reception in which a station is received at two different positions of the tuning dial. A second type of spurious response also frequently occurs; it is caused by harmonics of the local oscillator. These harmonics beat with strong signals being received at frequencies other than that indicated by the dial, and produce the intermediate frequency with the result that the unwanted stations are heard in the output.

There is another type of spurious response, called pseudoimage frequency, which is a strong signal beating with the fundamental

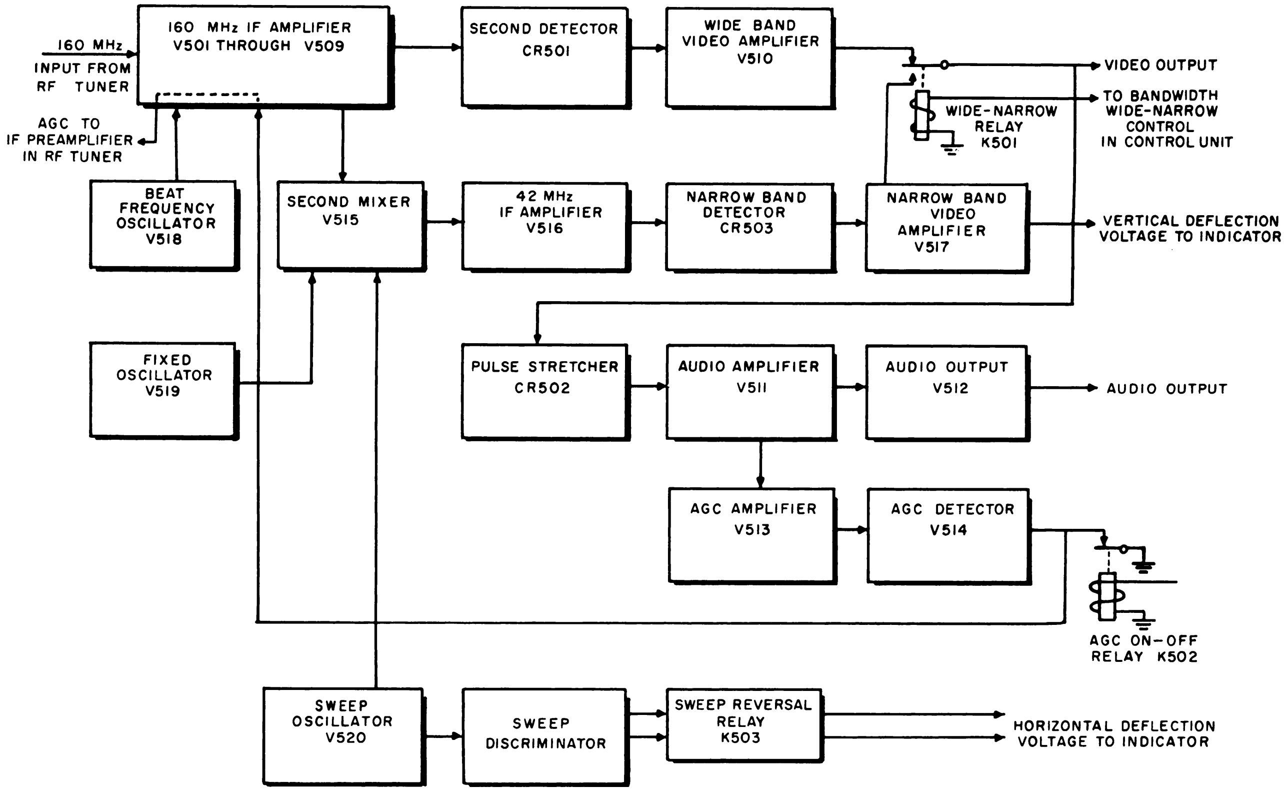

160 MHz
INPUT FROM RF TUNER
160 MHz IF AMPLIFIER V501 THROUGH V509
SECOND DETECTOR CR501
WIDE BAND VIDEO AMPLIFIER V510
VIDEO OUTPUT
TO BANDWIDTH WIDE-NARROW CONTROL IN CONTROL UNIT
WIDE-NARROW RELAY K501
AGC TO IF PREAMPLIFIER IN RF TUNER
BEAT FREQUENCY OSCILLATOR V518
SECOND MIXER V515
42 MHz IF AMPLIFIER V516
NARROW BAND DETECTOR CR503
NARROW BAND VIDEO AMPLIFIER V517
VERTICAL DEFLECTION VOLTAGE TO INDICATOR
FIXED OSCILLATOR V519
PULSE STRETCHER CR502
AUDIO AMPLIFIER V511
AUDIO OUTPUT V512
AUDIO OUTPUT
AGC AMPLIFIER V513
AGC DETECTOR V514
AGC ON-OFF RELAY K502
SWEEP OSCILLATOR V520
SWEEP DISCRIMINATOR
SWEEP REVERSAL RELAY K503
HORIZONTAL DEFLECTION VOLTAGE TO INDICATOR

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Figure 20-3.—Mixer amplifier block diagram.

IF frequency. Since one of the primary functions of the receiver is to enable the operator to determine the frequency of an intercepted signal by means of the dial reading, some device is needed to assist him in distinguishing true signals from spurious responses. For this purpose, wave-trap stubs or tunable filters are often used in conjunction with these receivers. The wave-trap stubs have a dial calibrated in frequency and can be switched into or out of the antenna lead-in. When the trap is in the circuit and tuned to the frequency of an incoming signal, the signal is filtered out and disappears from the output. By means of the calibration on the wave-trap, the operator can decide whether or not the signal frequency is actually that indicated by the dial reading at which he receives it. Generally, ECM receivers used in the fleet today have image rejection ratios sufficient to permit direct dial readings.

Automatic Search Receivers

Modern ECM receivers use automatic tuning. The receiver's tuning section is driven by an electric motor which tunes the receiver across its entire tuning range. The tuning is continuous; that is, when the upper end of the tuning range is reached, the motor automatically reverses and the receiver is tuned down to the lower end of the band where again the motor reverses and the receiver is tuned to the upper end of its range.

"Fully automatic" search receivers are similar in operation to those called automatic. However, there is one major difference. This difference is that fully automatic search receivers automatically stop tuning operations when a signal is detected. (NOTE: This is usually referred to as receiver lock-on.) The signal may then be observed and its frequency noted by the operator. When the operator completes his observation, a button is pushed (on the control box) and the tuning drive again starts through its tuning sequence from the point at which it was last locked.

Panoramic Adapters

Panoramic adapters are specialized indicators. Used for monitoring a wide range of frequencies, they provide visual displays of the signals intercepted by the search receiver. The signal indications appear on the screen of a cathode-ray tube. The station to which the search receiver is tuned appears as an inverted-V deflection at the center of the screen; and signals above and below this frequency show similar deflections to the right or left of center, depending on their values. The amplitude of any deflection is determined by the strength of the corresponding signal, so that the panoramic screen provides a plot of signal intensity versus frequency. (Signal intensity is indicated on the vertical axis, and relative frequency is represented on the horizontal.)

In search operations, the panoramic adapter is used principally as a tuning aid since the signals from many stations are indicated simultaneously. It can also be used to determine the types of modulation of intercepted signals and for observing the effects of the search aircraft's own jamming emissions.

INTERPRETATION OF PATTERNS.—Since a comparatively large number of signals may be observed simultaneously on the screen of the panoramic adapter, the instrument has great value in detecting enemy transmissions. Furthermore, the experienced operator can obtain additional information concerning the nature of the transmissions by inspection of the patterns. The oscillograms produced by several types of signals are shown in figure 20-4.

A constant carrier appears as a deflection with fixed height as shown in (A) of figure 20-4. Amplitude-modulated carriers appear as deflections which vary in height. If the modulating frequency is high, the sideband frequencies appear separately, causing pips on either side of the carrier deflection. Modulation with a single audio tone produces the pattern shown in (B) of the figure. A frequency-modulated carrier appears to wobble to the side. When the carrier is frequency modulated by voice or music, the appearance is a number of deflections which spread across a variable band as in (C). Pulse modulation gives the pattern shown in (D) when the pulse repetition frequency is considerably greater than the rate of sweep of the indicator beam.

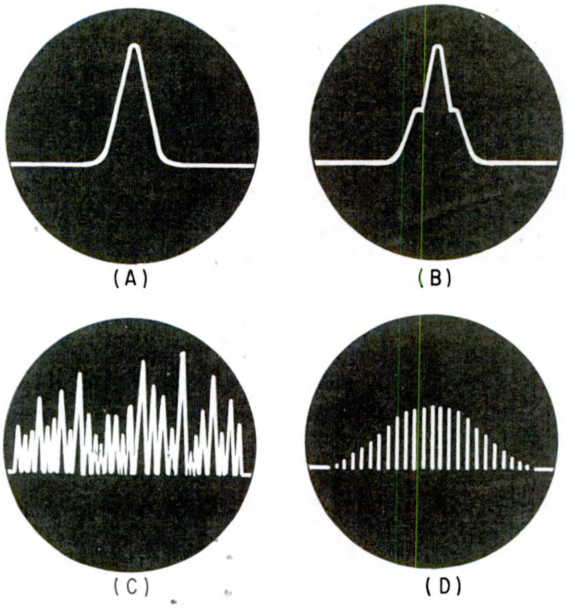

Figure 20-4.—Panoramic adapter patterns.

A CW signal appears and disappears with the keying of the transmitter. Two signals which are near enough in frequency to produce an audible beat note appear on the screen as a single carrier which varies in amplitude at the beat frequency. Noise voltages which vary regularly produce deflections which move across the screen in either direction, the motion being caused by the fact that the noise pulses are not synchronized with the panoramic sweep. Noise and interference, such as static bursts which are not periodic, produce irregular deflections and flashes along the length of the screen.

If image reception takes place in the associated receiver, the image signal has the same sort of appearance as the true signal. However, when the receiver tuning dial is rotated, the image pip moves in the direction opposite to that of the true signal deflection.

PULSE ANALYZERS

Pulse analyzers are used in ECM operations for measurement of the pulse repetition frequencies and pulse widths of radar signals detected by search receivers. The analyzer can also supply information concerning lobe switching, rotation rates, and beam widths of radar transmissions. In many pulse analyzers, the data are presented visually by means of cathode-ray tubes, although in some the pulse width and PRF values are indicated on meters. An example of the type using a cathode-ray tube as an indicator is shown in block diagram form in figure 20-5. The equipment shown is a synchroscope. (A synchroscope differs from an oscilloscope in that an input signal must be used to trigger the sweep. In actual practice this signal results from the interception of an enemy transmission.)

This analyzer's cathode-ray tube is unique in that it contains five separate electron guns within one glass envelope. The horizontal beam of each electron gun sweeps at a different frequency. Therefore, the signal that appears is shown on five different time bases. Various scales are engraved on the cursor so that desirable readings may be obtained. The two top traces show wide pulses so that pulse width may be observed. The three bottom traces indicate pulses repetition frequency.

The pulse from the search receiver follows two paths after it is fed into the pulse analyzer. One path leads to a pulse shaper which produces pulses having the same width and repetition frequency as the received video signal, as well as constant amplitude and rise time. The shaper output starts the horizontal sweeping action that unblanks each scope.

The other path is through a delay line to the vertical plates of the five guns in the CRT. This delayed signal is the deflecting voltage which produces a deflection of each time base so that signal characteristics are indicated. The delay is for a very short period of time. This insures that the leading edge of the pulse will be presented on the scope. In the last three electron guns, the horizontal sweep frequency is sometimes so low (slow sweep) compared to the signal frequency that the signal does not appear on the CRT. (Signal pulses appear but are too narrow to be seen.) In this case a stretching circuit can be switched in. The stretching circuit broadens, or stretches, the signal enough so that it shows on the scope.

When lobe switching is used by the enemy, the pulse width pattern appears as shown in figure 20-6. Because of lobe switching, the trace is not steady but appears to jump up and down. Although figure 20-6 shows a lobe-switching pattern on only one line, in actual practice the pattern would appear on all five lines.

Cathode-ray oscilloscopes and audio oscillators are sometimes used to measure the repetition frequencies of radar pulses when a pulse analyzer is not available. The pulse repetition frequency is determined from the patterns which result from application of the received signal to the vertical deflection plates of the scope while sweeping the beam horizontally with the output of the calibrated audio oscillator.

The information derived with these various types of search equipment consists of the characteristics of the enemy signals. These properties form the basis for estimating the capabilities and weaknesses of the electronic installations and for devising effective jamming techniques to be used against them.

DIRECTION FINDERS

One of the essential things to learn about any radar or radio station operated by the enemy is its exact location. In search intercept flights this information can be obtained by the use of airborne ECM direction finders which have been developed for this particular purpose. The enemy transmitter reveals its location as long as it is sending out radio waves; but the problem of analyzing the emissions is complicated by the fact that the enemy may choose either vertical or horizontal polarization. Consequently, the direction finder must be capable of receiving either type of transmission.

In ECM direction finders designed for higher frequencies, typical equipments employ continuously rotating antennas which are highly directional. Signals received are displayed on a cathode-ray indicator on which is presented a polar diagram of reception obtained throughout 360 degrees of rotation of the antenna. The pattern contains a major lobe which indicates the relative bearing of the station whose signals are displayed.

To locate a particular transmitter, the operator makes several readings of its relative bearing by means of the direction finder display. Each of these readings is called a "cut." With each cut, the operator records the time and the

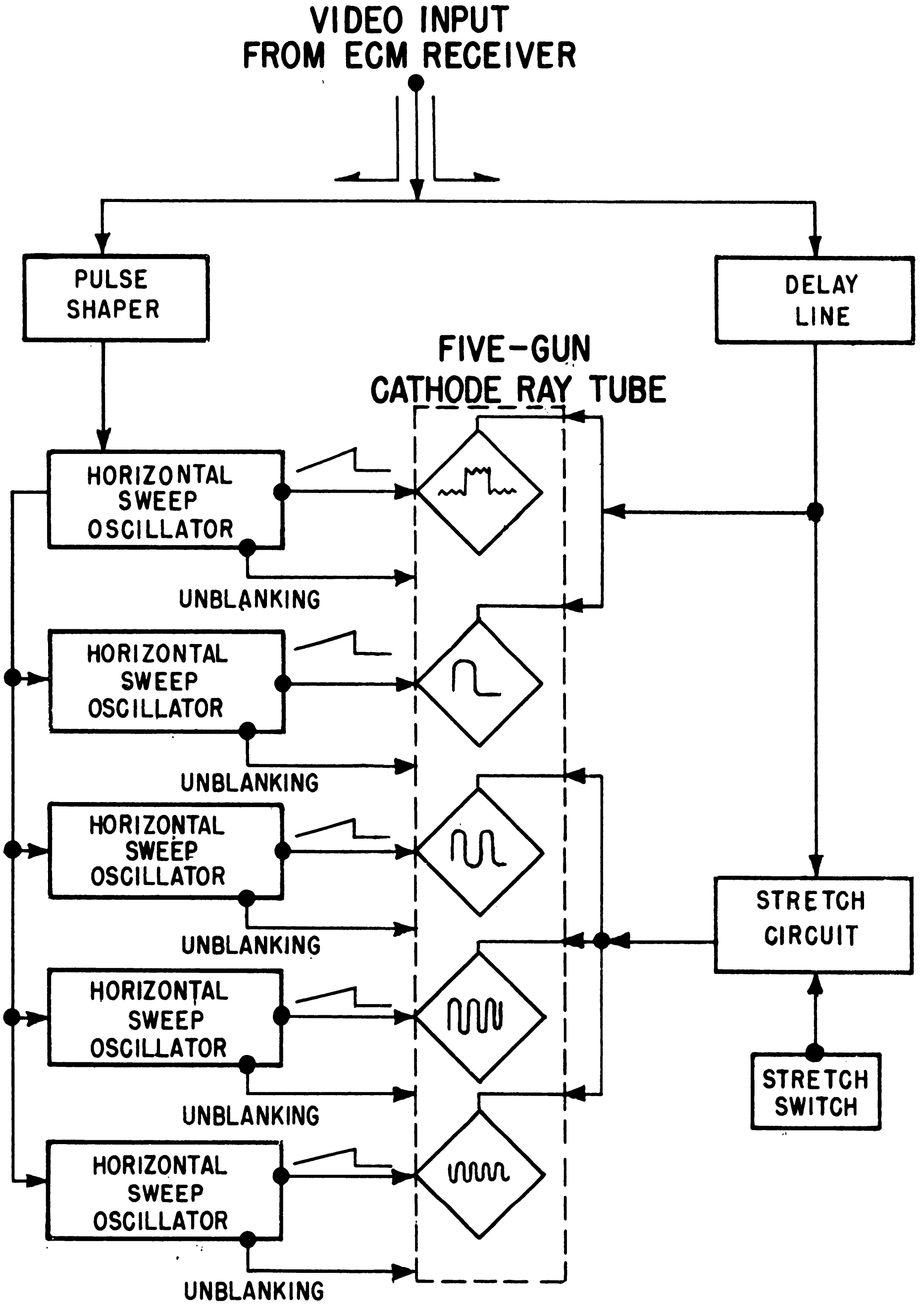
VIDEO INPUT
FROM ECM RECEIVER
PULSE SHAPER
DELAY LINE
FIVE-GUN CATHODE RAY TUBE
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
HORIZONTAL SWEEP OSCILLATOR
UNBLANKING
STRETCH CIRCUIT
STRETCH SWITCH

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Figure 20-5.—Block diagram of a pulse analyzer.

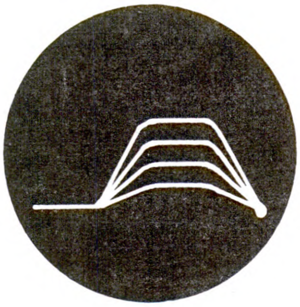

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Figure 20-6.—Pulse width pattern obtained from lobe switching.

compass heading of the aircraft. This information is given to the navigator, who can determine, from the track of the flight, the exact location of the aircraft corresponding to each direction-finding cut. The track of the aircraft is then drawn on a chart and along it is marked the position at which each cut was made. Through each position a line is drawn, which makes an angle with the track equal to the recorded value of the relative bearing for that point. The intersection of the lines on the chart indicates the position of the enemy transmitter.

The direction finder display can also be used to learn the types of modulation of intercepted signals, to estimate pulse widths and repetition rates, and to determine the polarization of radar antennas.

Indicator Patterns

The cathode-ray screen of ECM direction finders employing visual displays shows the operator a polar graph on which the strength of received signals is plotted against relative bearing. To form the patterns, signals are received by the rotating antennas which are synchronized with the sweep of the cathode-ray beam of the indicator tube. Signals are received from a very small sector at any one time and are amplified and detected in the search receiver. Video pulses from the receiver are applied to the direction finder for further amplification. When they are applied to the indicator tube, they produce patterns similar to those shown in figure 20-7.

With each video pulse the electron beam in the CRT is deflected outward from the center of the screen; thus the length of the trace indicates the relative signal strength. The angular direction of each trace line represents the direction in which the antenna is pointing when the corresponding signal is received. The indicated bearing can be either relative or true, depending on the type of direction finder being used.

To read the relative bearing of a station when its signal is displayed, the operator uses a movable mask on which is inscribed an arrow; the mask is fitted over the indicator screen. The operator rotates the mask until the arrow bisects the major lobe of the pattern and then reads the relative bearing on a graduated scale surrounding the face of the indicator tube. In an indicator that reads true bearing, the azimuth scale is automatically rotated around the outer rim of the CRT.

SIGNAL CHARACTERISTICS.—Signal characteristics which create a distinctive pattern on the CRT are radar PRF, relative signal amplitude, modulation characteristics, and polarization. The best way to gain skill in interpreting the great variety of patterns that may possibly appear on the CRT is by observing known scope patterns (characteristics). (Refer to figure 20-7 for illustrations of representative scope patterns.) A certain amount of deduction will inevitably be necessary because of the almost infinite number of possible pattern combinations.

The pattern shown in (A) of figure 20-7 results from the signals of a search radar located dead ahead of the aircraft. The PRF is a comparatively low value as indicated by the wide spacing of the traces. Bright tips appear at the trace ends which are characteristic of pulse-modulated waves such as those emitted by almost all radar transmitters. In (B) of the figure the indicator pattern is that resulting from simultaneous reception of two radars on different bearings.

In (C) of figure 20-7 the pulses are grouped in sets of different length, indicating a lobe-switching radar, possibly a fire control system. The pattern varies with the location of the search aircraft relative to the direction of the radar lobes. When the pulse groups form a smooth pattern with all traces of equal length, the indication is that the aircraft is being bracketed by the switching lobes of the radar and that the guns controlled by it are probably trained on the observer.

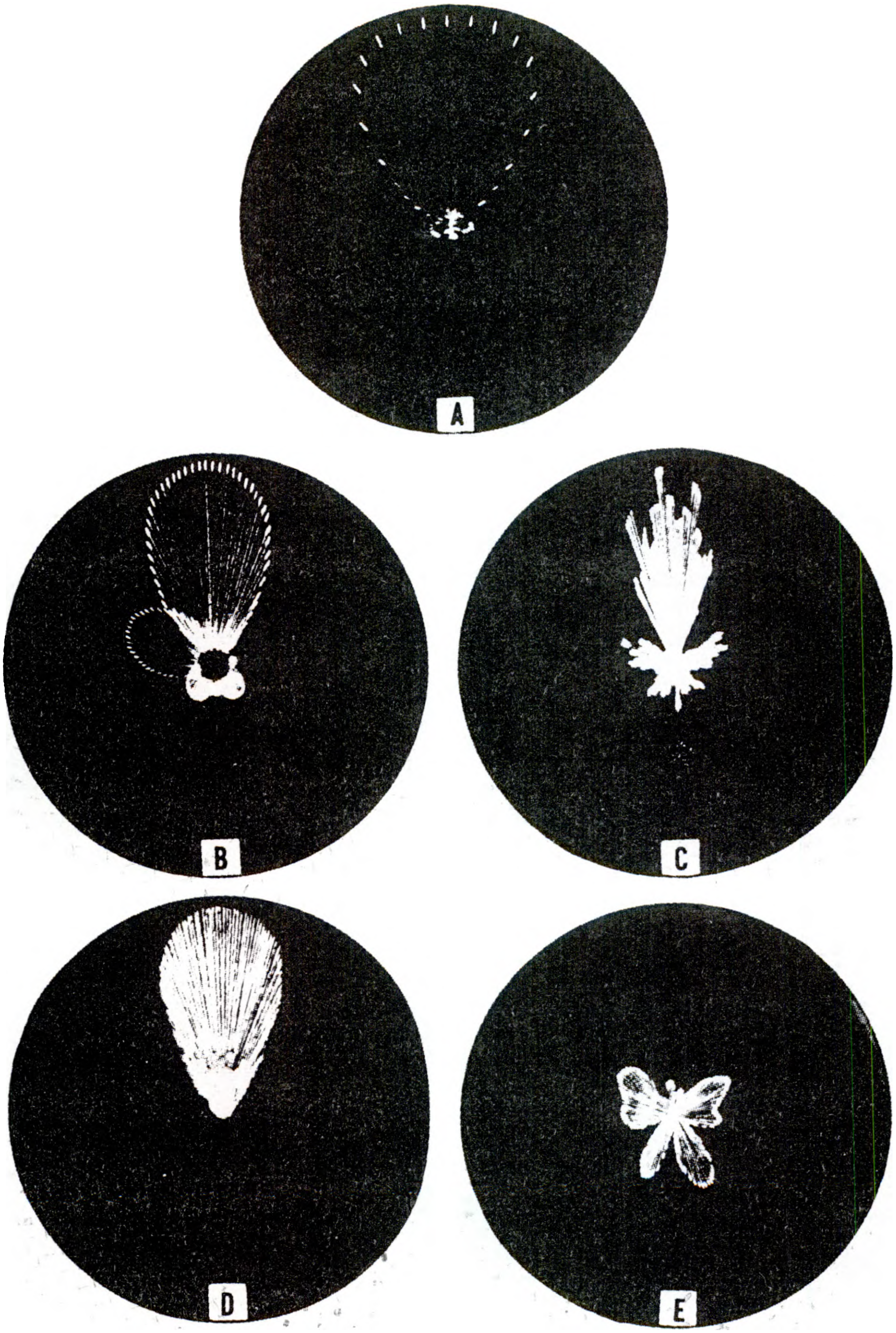

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Figure 20-7.—Direction finder patterns.

A signal from a communications transmitter employing voice modulation is shown in (D) of the figure. Communication signals are easily identified by the fact that they do not produce bright tips on the trace lines and the pattern has a fuzzy appearance. The pattern shown in (E) does not display a marked major lobe and indicates that the polarization of the direction finder antenna is different from that of the polarization of the received waves.

In radar patterns, the lengths of the bright tips on the trace lines provide a means of estimating the pulse width. With the unit whose display patterns are illustrated in (A) and (B) of figure 20-7, the ratio of the bright length to the total trace length expressed in percentage is approximately equal to the pulse width in microseconds. For example, if the bright tip is about 5 percent of the trace length, the pulse width is approximately 5 microseconds. The pulse repetition rate of the radar can be estimated roughly by the amount of spacing between the trace lines; however, the spacing is governed to some extent by the rate of rotation of the receiving antennas as well as by the PRF of the signals.

Equipment Components

An example of ECM direction-finding equipment which provides the type of display discussed above is illustrated in figure 20-8. This direction finder, when used with suitable radio or radar receivers, provides visual indications on a CRT. Such indication gives the true bearing of the received radio or radar signals. The direction indication is converted to true bearing by an azimuth scale which rotates around the outer rim of the CRT. Other information can be obtained from the CRT picture, such as approximate PRF, relative signal amplitude, modulation characteristics, and signal polarization.

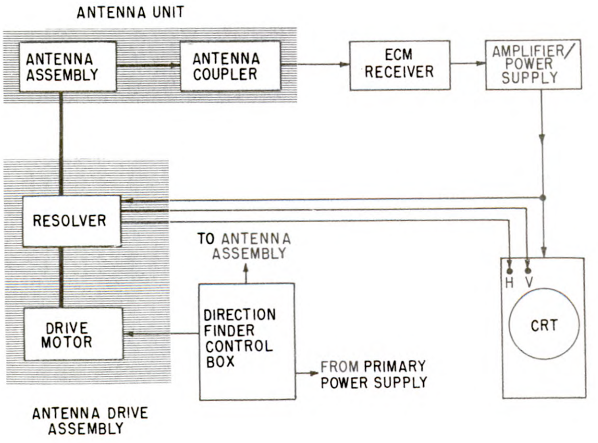

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Figure 20-8.—Block diagram of an ECM direction finder.

The typical direction finder consists of five major units. These are an antenna unit, an antenna drive assembly, an amplifier/power supply unit, an azimuth indicator, and a control box. The type of receiver used was previously discussed. Its output video signal is supplied to the amplifier/power supply unit; this unit consists of a video amplifier and the power supply necessary to operate the direction finder.

The azimuth indicator unit contains a small CRT indicator. It has external adjustments for controlling the vertical and horizontal positioning, and the focus and intensity. The indicator unit also has a torque unit and a gear train. These rotate the moving scale for the azimuth reading.

The control box is located at the operator's position. It provides means for selecting the proper antenna, varying the speed at which this antenna is rotating, switching the polarization of the antenna, varying the gain of the video amplifier, and turning the primary power off and on.

The antenna drive assembly has a d-c motor and a gear train to drive the resolver and the antenna. The video signal from the intercept receiver is amplified and then passed through the resolver which is geared to the antenna drive shaft. This resolver voltage is then delivered to the plates of the CRT. It impresses on the tube a signal which is a radius vector rotating about the center of the CRT. The rate of rotation is the same speed as the antenna's rotation.

The combined function of all of the units that make up the direction finder is to produce a CRT pattern of the received radio or radar signal. This pattern is produced in such a manner as to indicate the direction from which the signal is being received and then to convert that direction indication into a true bearing by means of the rotating azimuth scale.

ANTENNAS

The antenna assembly is an essential unit of an ECM installation. Ideally there would be two directional antennas for each frequency range, one polarized vertically and the other polarized horizontally. From the standpoint of space and weight this is impractical for aircraft installations. Aircraft ECM antennas are constructed so that they cover a broad band of frequencies and possess different polarization characteristics. Also, more than one antenna is mounted on the same antenna base. In many of the units, the assembly includes built-in impedance-matching sections.

Direction Finding Antennas

Figure 20-9 shows a type of construction that is used in ECM direction finder antennas. Notice that there are three separate directional antennas. This practice makes possible the coverage of different frequency ranges. Also notice the different types of polarization used.

The three antennas are mounted on the same disk and may rotate through 360 degrees. Only one antenna is active at a time as selected by a polarization switch on a remote control panel. This polarization switch selects the frequency band desired and the type of polarization used with the selected antenna. The feed of the parabolic reflector antenna is rotatable through a 90-degree angle to provide for reception of both vertically and horizontally polarized signals.

Search Antennas

Since enemy signals may appear over very wide ranges of frequency, the antennas used with ECM search receivers must necessarily be very broad in frequency response. To insure this, the antennas are made thick and stubby in structure so that the inductance value is low. As a result, the antenna stores very small amounts of energy and has a low Q with the broad frequency response which is characteristic of all low-Q circuits.

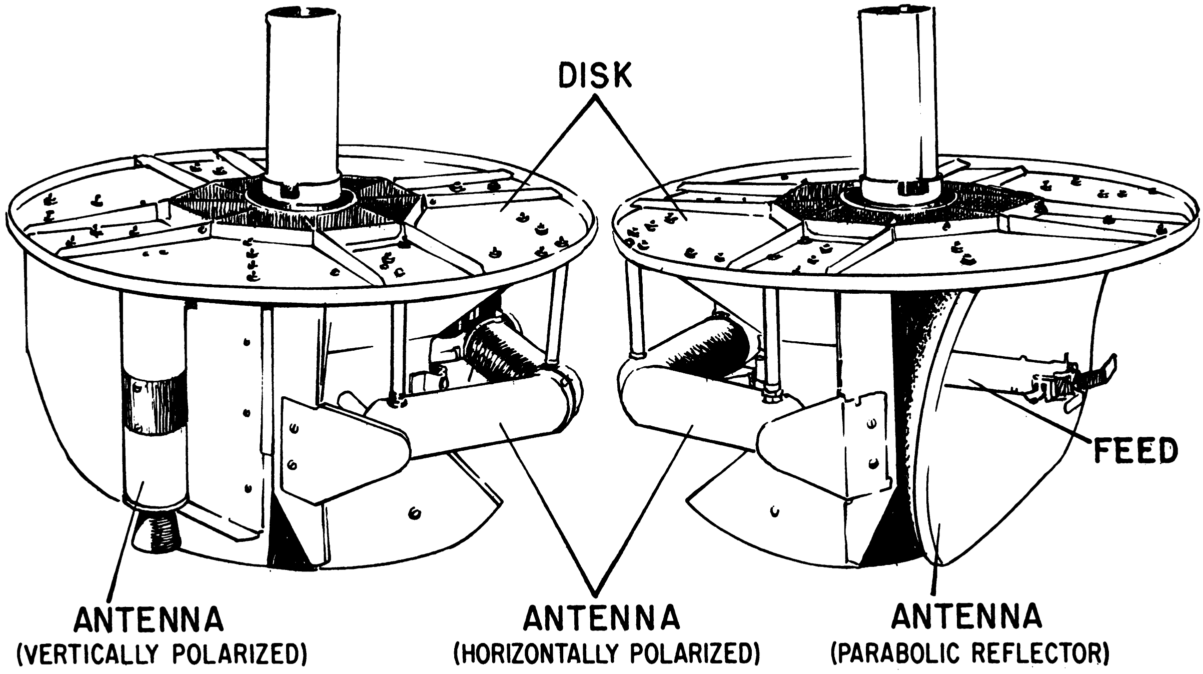

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Figure 20-9.—Direction finder antennas.

A type of ECM antenna used with airborne search receivers is shown in figure 20-10.

The stub antenna consists of a wooden mast about 22.5 inches in length which is covered with a thick metal plating. The plated area in a typical installation is connected to a receptacle for attachment to a 50-ohm coaxial cable.

ACTIVE ECM EQUIPMENT

Active ECM actions can be detected by the enemy and tend to prevent him from making effective use of his equipment. These actions consist of jamming, of deception, or a combination of both. The equipments used are of two general types: electronic and nonelectronic. The electronic type includes jamming transmitters and pulse-repeating receivers. The jamming transmitters are used to produce interference with radar, navigation, and communications reception so that enemy receiver are subjected to obscuring and confusing radiations. Pulse-repeating devices are used for deception and are similar to radar beacons. They receive radar signals and respond with pulses which give the enemy false information concerning bearing or range.

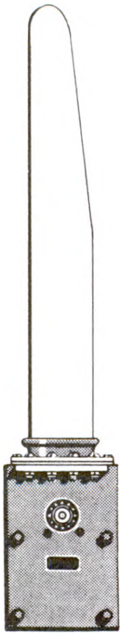

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Figure 20-10.–Stub antenna.

Nonelectronic jamming is often accomplished by the use of strips of metallic foil released from aircraft (and sometimes fired in projectiles). The falling strips intercept radar waves and reradiate them, causing numerous false targets to appear on the enemy radar-scope so that the operator is unable to detect desirable targets and fire control radar is unable to see attacking aircraft.

Before active countermeasures can be undertaken, an extensive search, or intercept, campaign must be made to learn what types of electronic equipment are in active enemy use and the purposes for which they are employed. To gain this information, intercept flights are made in aircraft which carry special ECM equipment. With the equipment, the ECM operator tunes in signals from enemy units and measures their characteristics. He records the results in a log or acquires tape or film records which are later submitted to tactical officers for analysis and evaluation. The information gained is then used in planning active countermeasures, such as jamming, for directing control of radiation from friendly units, and for devising means of evading detection by the enemy equipments reported.

JAMMING TRANSMITTER

Electronic jammers are tunable radio transmitters used for producing interference. The jammer radiates a carrier wave modulated with audio voltage suitable for drowning out reception or overloading enemy receivers. One of the most effective kinds of modulation for this purpose is random noise similar to the background disturbances heard in sensitive radio receivers when no station is being received. Noise makes a very desirable jamming signal since it distributes energy over a wide range of frequencies and cannot be filtered without loss of the desired signals. It is also difficult to recognize as manmade interference because of its similarity to atmospheric static impulses. A second type of jamming modulation is caused by sweeping the carrier over a wide range of frequencies at an audio rate. Another type consists of a repetition of several audio tones, three to five in number, which give rise to a wailing sound when received.

When operated against radar receivers, the ECM jammer works at a distinct advantage since the echoes returned from most targets are very weak, and the jamming signal usually competes only with low-level radar signals. An output power in the order of tens of watts can effectively overcome radar pulses originally emitted at a peak power in the order of kilowatts. As a result, low-powered transmitters can sometimes jam enemy radar reception at far greater than the maximum effective range of the radar. However, it is often necessary that the jamming signal be radiated continuously, and that the output power of the ECM transmitter be as great as the average power of the radar it can successfully jam. Because of these requirements, adequate cooling must be provided. This is usually accomplished by fans, but may be accomplished by other means such as a water jacket around the transmitter to remove the heat.

ECM transmitters are used in one or two ways, called spot jamming and barrage jamming. In the first of these, the operator tunes the jammer to the exact frequency of the receiver to be victimized by first tuning in the enemy signal with a search receiver. He then adjusts the output of the transmitter until the two signals coincide in frequency. Tuning for spot jamming is usually done in flight. Barrage jamming is accomplished by using a number of transmitters as in a formation of aircraft with each aircraft carrying at least one jamming transmitter. The units are pretuned to frequencies which differ by about 3 megahertz, a typical value of the bandwidth of an ECM transmitter. When all units are turned on, a wide range of frequencies is completely covered.

An example of an airborne jamming transmitter is shown in block diagram form in figure 20-11.

The typical countermeasures transmitting set is an airborne noise-modulated transmitting system. It is designed to jam enemy radar signals of any polarization over a wide frequency range. Such a transmitting set is suitable for use as a spot or sweep jammer, and for manual use with currently used ECM receivers. This set is a lightweight, airborne, noise-modulated jamming system which may be controlled either automatically or manually. The jamming transmitter is similar to the ECM receiver in that it covers a wide frequency range by using plug-in tuning heads. The noise source is generated by a special type tube. This noise is amplified through several stages of video amplification. This broad band of frequencies is fed to a pair of high-powered modulator tubes.

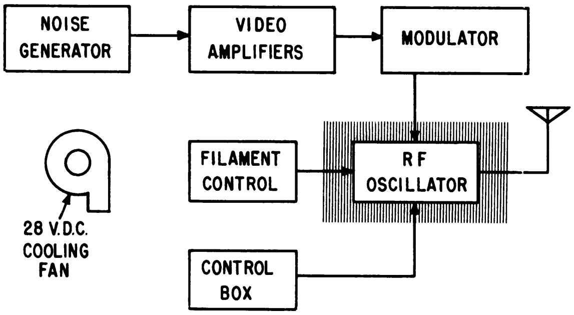

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Figure 20-11.—ECM jamming transmitter.

The RF oscillator stage is the stage that is replaced when different tuning heads are used. Each stage contains a mechanically tunable magnetron oscillator which is modulated by the generated noise signal. The cathode filament of the magnetron receives enough power from back bombardment of electrons, when plate voltage is supplied, to materially shorten the life of the magnetron. Therefore, a-c power applied through the filament transformer must be varied to keep filament temperature constant. This is the function of the filament control unit.

The operator selects the mode of operation of the transmitter with the control box. Transmitter frequency may be changed manually by the operator turning a knob, or it will change automatically if set for automatic operation. A switch is incorporated on the control box which allows the operator to switch out the noise generator. When this is done the transmitter produces CW transmission; otherwise the output is modulated. The purpose of this switching arrangement is to produce another confusion factor for the enemy.

Automatic Jamming Equipment

Automatic jamming equipment consists of an automatic search receiver and an automatically tuned jamming transmitter.

The sequence of operation is as follows: The receiver searches a desired frequency range, and when a signal is detected, the receiver locks-on this signal. As the receiver locks-on, the transmitter is automatically tuned to the same frequency. When the transmitter tuning cycle is completed, the transmitter is then automatically keyed to begin jamming operation. Different types of jamming (pulse, noise, etc.) may be produced by the transmitter. The particular type of jamming to be used by the transmitter is preselected by the ECM operator.

It should also be noted that this system may be switched to manual operation. This enables the ECM operator to manually perform the sequence of steps in the operation of the system.

ANTIJAMMING CIRCUITS

An ECM development relating to active jamming is the antijamming circuit often installed in receivers, particularly those in radars. The antijamming device is designed to decrease the effectiveness of enemy jamming and hence is called a "counter-countermeasure." These circuits have two uses: They prevent interfering signals from overloading the receiver, and tend to separate the desired signals from the jamming signals. Typical antijamming circuits are simple inductance-resistance filters of the high-pass type. The effect of the circuit, which is usually associated with the video detector section in the receiver, is to pass the high frequencies present in the signal and suppress low-frequency components. As a result, the leading edges of pulses are accepted by the circuits following the filter and large blocks of jamming voltages are excluded from the video amplifier circuits.

NONELECTRONIC JAMMING

WINDOW and ROPE are code names for strips of aluminum foil used for nonelectronic jamming. The strips act as reflectors; and when released from aircraft, they return echoes to enemy radar receivers.

Window

Window (also called chaff) is tuned material. The strips of foil are cut to one-half wavelength of the radar signal to be reflected, and each strip acts as a resonant dipole antenna which intercepts and reradiates energy. The dipoles are packaged in cardboard folders which are either dropped manually or released by automatic window dispensing devices. Each package contains foil cut for a certain frequency so that a folder may contain from 50 to 200,000 dipoles, depending on the wavelength of the system for which it is prepared. Typical bundles contain several thousand strips, and weigh less than two ounces. When the package is released, it opens so that the dipoles scatter into the air and begin falling at the rate of about 400 feet per minute.

Skilled radar operators can distinguish between aircraft pips and a single window echo; for this reason, window is seldom dropped in isolated packages. Usually, a lead aircraft lays down a path consisting of many packages spaced at intervals of 1,000 feet or less. The aircraft which follow in the formation fly through the resulting clouds of reflectors, and enemy operators find it difficult to separate the single pip of an aircraft from the mass window echoes. Thus, the following aircraft are protected from radar-controlled antiaircraft fire and concealed from air search radars. On the radarscope, the dispensing aircraft appears as a pip which divides into two parts. The pulse representing the aircraft moves across the screen while additional echoes appear behind it and remain stationary. As the dipoles disperse in the air, the stationary pip grows into a shapeless mass in which the following aircraft are practically invisible. Aircraft must be inside the cloud of reflectors to be hidden; those behind but not within the cloud can be detected by radar waves which pass through the strips.

Window is often used in conjunction with electronic jamming transmitters to protect a formation of aircraft from radar-controlled gunfire.

Rope

Rope is similar to window in that it is a confusion reflector, but it differs from it in length and also in the fact that it is untuned. Strips of rope are aluminum ribbons about 400 feet in length and about one-half inch in width. The ribbons are used as nonresonant reflectors for jamming low-frequency radars and are also employed in regions where the enemy operates many units which differ considerably in frequency. The rope material is dispensed in the form of a roll, one end of which is attached either to a small paper parachute or to a square of cardboard. The rolls equipped with parachutes assume a vertical position while falling and reflect waves that are vertically polarized. Those attached to cardboard squares unwind and float downward in a horizontal position, thereby reflecting horizontally polarized radar pulses.

CHAFF DISPENSERS

Chaff dispensers, together with the dispenser control (fig. 20-12) are designed for use with a variety of military aircraft. Their purpose is to carry and dispense packaged chaff material for jamming and deceiving enemy radar equipment. They are similar in size and shape to a droppable fuel tank, and have a large container inside for carrying the chaff material.

The chaff material is held firmly in place in the container by the package holddown assembly. (See fig. 20-13). The holddown assembly is in the DOWN position (after loading) until ready to dispense the chaff material. To start the operation the operator moves the DISP-OFF-HOLD switch from HOLD to the DISP position, energizing the holddown motor and raising the holddown pad until the pad actuates an up-limit switch (normally open) supplying power to the drive motor. The drive motor pulls the tape, which carries the chaff material aft over the idler rollers and into the airstream coming from two air ducts in the dispenser body. The airstream deflects the chaff material down and out of the opening in the aft underside of the dispenser. A tape cutting feature is incorporated in the dispenser to prevent long streamers of chaff tape fouling the packages or tail assembly of the carrying aircraft. An automatic motor disconnect switch is provided to automatically open the motor circuit when all the chaff packages have been dispensed.

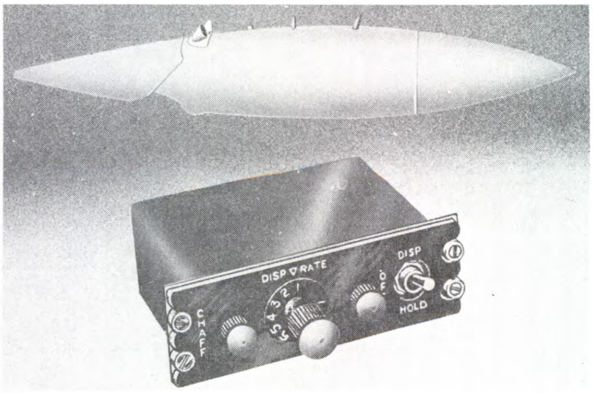

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Figure 20-12.—Dispenser and control.

The dispenser consists of three detachable sections which latch together to form a streamlined fairing. The center section contains the chaff package container, package holddown mechanism, and dispenser drive mechanism. Some models include a tape cutting assembly incorporated into the drive assembly. The nose and tail sections steamline the unit and detach to facilitate loading and servicing. (see fig. 20-13.)

Dispenser Control

The dispenser control (fig. 20-13) is installed within the aircraft either on the cockpit panel or in some convenient location, and contains all necessary controls for the operation of the dispensing system. The control consists of a DISP-RATE selector, a DISP-OFF-HOLD switch, and two panel light assemblies (connected to the aircraft cockpit panel light circuit). The DISP-RATE selector consists of a double wafer, a ten-position switch, a knob, and a plastic dial.

The DISP-OFF-HOLD control is a three-position toggle switch, spring loaded from HOLD to OFF positions. The DISP position controls the power to the dispensing mechanism, and the HOLD position actuates the package holddown mechanism within the dispenser.

Maintenance of the dispenser and the dispenser control and loading of the chaff materials within the dispenser are the responsibility of the Avionic's personnel.

The dispenser is approximately 117 inches long and 18.4 inches in diameter at its thickest part. The weight when empty is 86 pounds as compared to 210 pounds when loaded. The dispenser is loaded on a bomb rack, and receives operating power from the aircraft's 28-volt d-c supply through the dispenser control.

Figure 20-14 shows an internally mounted chaff dispenser. Two of these units are normally installed in one aircraft. Each dispenser unit consists of thirty discharge tubes joined together in parallel. One end of each tube is open and the other end is closed. The closed ends contain

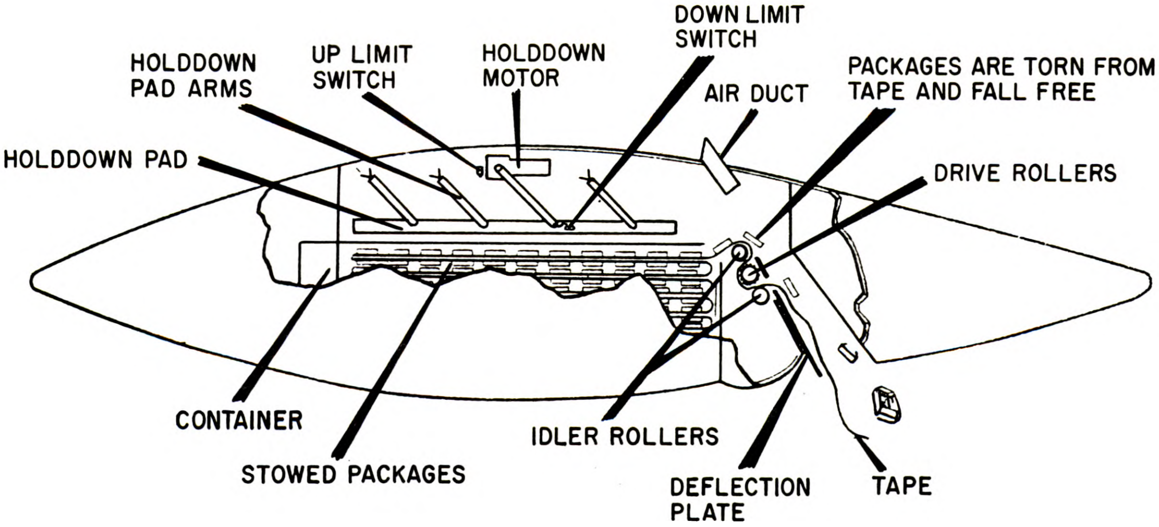

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Figure 20-13.–Principles of operation (chaff dispenser).

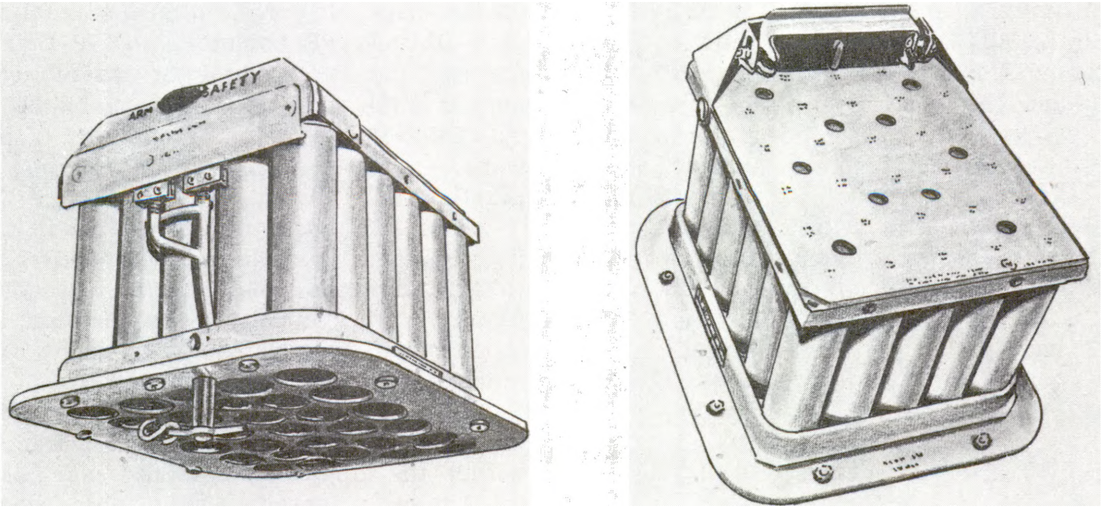

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Figure 20-14.–Chaff dispensers.

electrical contacts which operate an electrical initiator. The open ends are connected to a platform which serves as a mounting flange for the unit. The initiators serve as the propelling force to discharge the tubes load through the open end into the atmosphere.

This system has a control unit (not shown) that contains an intervalometer, a repeat cycle timer, and a time-delay relay for programming. The programing is accomplished by positioning two front panel mounted switches. One switch sets the desired sequential timing rate and the other sets the desired number of automatic sequenced ejections. Since this unit is mounted in an area not accessable to the pilot, these settings must be determined and adjusted before flight.

An ON-OFF power switch to control the power to the system, a momentary "auto" switch for initiation of an automatic cycle dispensing operation, a momentary "single-fire" switch for initiation of a single-fire dispensing operation, and a solenoid-operated numerical counter to register each pulse from the dispensing set and read out the number of loads (chaff) remaining in the dispenser units are located in the cockpit for pilot control.

ECM TEST EQUIPMENT

Most of the test equipment used in the maintenance of ECM equipment is common to many other types of electronic equipment. The test equipment that may be considered special ECM test equipment comprises the RF signal generator(s) used to aline the ECM receivers.

Each generator used usually covers only one relatively small band of frequencies. Several generators are needed to maintain a complete set of ECM receivers. These RF generators (above VHF frequencies) produce various kinds of modulated RF signals. For example, continuous wave (straight RF), modulated continuous wave (audio-tone modulated), or pulse modulation may be selected. With the tone modulation, various tone frequencies may be selected. With the pulse modulation, various pulse widths and different pulse repetition frequencies may be selected.

CHAPTER 21

INFRARED DETECTION

Infrared, or IR as it is sometimes called, is assuming increasing importance in missile guidance, target detection, fire control, communications, and mapping. Like radar, infrared was developed and used for military purposes during World War II. Unlike radar, however, the use of infrared has received little publicity. In some military applications, infrared energy has advantages over radar. Infrared, used as a medium of communications, is usually less susceptible to counterdetection and interference than is radar or visible light. Infrared equipment is generally less complex than radar equipment used for similar tasks.

ELECTROMAGNETIC SPECTRUM

IR is a form of electromagnetic energy, with certain characteristics identical to those of light and RF waves. Among these characteristics, some of the more important ones are reflection, refraction, absorption, and speed of transmission. Infrared waves differ from light, RF, and other electromagnetic waves only in wavelength and frequency of oscillation.

The frequency of IR ranges from approximately 300,000 megahertz to 400 million megahertz. Its place in the electromagnetic spectrum (fig. 21-1) is between visible light and the microwave region used for high definition radars. This part of the spectrum is usually discussed in terms of wavelength, and it is generally accepted that the IR spectrum lies between 0.72 and approximately 1,000 microns (1 micron equals 0.0001 centimeter).

The IR portion of the electromagnetic spectrum is frequently divided into the following three parts:

1. The near infrared (NIR) which extends from the visible region out to around 1.5 microns.
2. The intermediate infrared (IIR) which extends from 1.5 to 5.6 microns.
3. The far infrared (FIR) which extends from 5.6 microns to microwave frequencies.

Some confusion in terminology exists because infrared energy is so close to the visible range of wavelengths in the electromagnetic spectrum. Thus, it is not uncommon to hear references to "infrared light," although the term is inaccurate. Infrared waves are also loosely referred to as heat waves, because of the well-known fact that a solid object subjected to radiation by infrared energy undergoes an increase in temperature. Heat differs from infrared waves in much the same way that electricity differs from radio waves.

INFRARED RADIATION

All objects above absolute zero (0° K or -273° C or -460° F) emit infrared radiation. Radiation from any given object is emitted over a wide range of wavelengths, but it reaches a peak at one particular wavelength. This point is of considerable interest in military applications, as will be shown later. Detection of infrared energy depends on the contrast between IR from the source under consideration and the radiation emitted by the background. A cold object with a warm background has just as good target definition as a warm object with a cold background.

There are a number of advantages in using IR for target detection rather than some other form of electromagnetic transmission. Among these are the following:

1. IR systems are passive.
2. Although IR systems can be confused, complete jamming is just about impossible.
3. Military targets are usually good sources of IR.
4. IR systems may be made smaller, lighter, less complex, and less expensive than other comparable systems.
5. IR systems have higher target resolution.

EMISSIVITY

One of the most useful concepts employed when working with IR is the "black body." A black body is defined as an object which absorbs all radiation incident on it. Conversely, the radiation emitted by a black body is the maximum possible for any given temperature. This black body is then a perfect absorber and

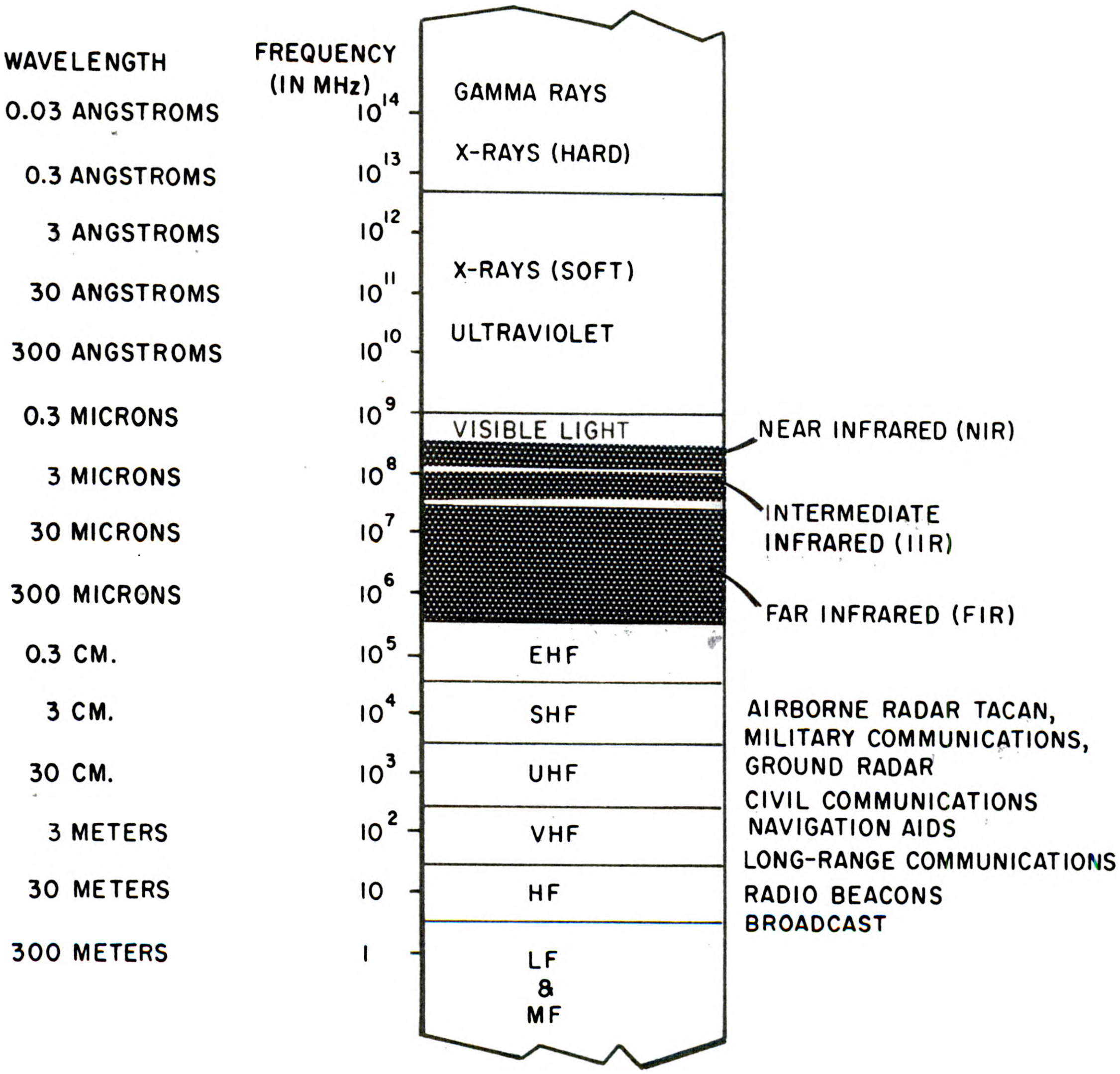

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Figure 21-1.—Electromagnetic spectrum, showing different wavelength units used in different bands of the spectrum.

radiator of IR at all temperatures and for all wavelengths.

In order to compare the radiation emitted by an actual source with that of a perfect radiator, the concept of emissivity is employed. Emissivity is defined as the ratio of the total radiation emitted by any object at any temperature (T) to the total radiation which would be emitted by an ideal black body at the same temperature. The emissivity of any object depends on the amount of energy its surface can absorb. If the surface absorbs most of the IR striking it, then it will emit a relatively high amount of radiation, and the emissivity of the object will be comparatively large. By the same reasoning, if the surface reflects most of the incident radiation, the object will have a relatively small emissivity. By definition, a black body has an emissivity of unity. Therefore, any other object will have an emissivity of less than one. Table 21-1 shows the emissivity of various surfaces.

Table 21-1.–Emissivities of various surfaces.

Surface	Emissivity
Black body	1.00
Lampblack	0.95
Painted	0.90
Steel, cold-rolled	0.60
Aluminum paint	0.25
Steel, stainless	0.09
Aluminum aircraft skin	0.08
Aluminum foil	0.04
Silvered mirror	0.02

Laws of Emissivity

The basic laws which describe the characteristics of IR were developed first for black body radiation, the ideal case, and then modified to describe the radiation from any source.

The most important parameter in determining the IR characteristics of any body is its temperature. As the temperature of an object changes, two specific changes in the IR characteristics take place: The wavelength where peak radiation occurs is shifted, and the total energy radiated varies with the fourth power of the temperature. These fundamental relationships are given by two laws which are discussed in the following paragraphs.

WIEN'S DISPLACEMENT LAW.–This law states that the wavelength at which maximum radiation occurs, λ_m is inversely proportional to the absolute temperature of the body. This can be expressed by

$$\lambda_m = \frac{K}{T}$$

where the wavelength is given in microns, and the constant (K) has a value (for a black body) of about 2,900. For example, a block of ice emits its peak energy at about 10 microns, while energy emitted from a jet aircraft engine peaks at about 3.5 microns. The relationship is shown in figure 21-2.

STEFAN-BOLTZMANN LAW.–This law states that the radiation intensity, E, is directly proportional to the fourth power of the absolute temperature, expressed as

$$E = \Sigma T^4$$

where E has dimensions of power per unit area, and Σ is the proportionality constant. In other words, if the temperature of an object is doubled, the radiation emitted from the object will be 16 times as much.

The Stefan-Boltzmann Law can be modified to include the emissivity factor; and by using the right units, the total radiation can be obtained by

$$E = \epsilon \Sigma T^4$$

where ϵ is the emissivity factor of the radiating surface.

A black body at an absolute temperature of 300°K (81° F) will radiate 46 milliwatts of power per square centimeter of its surface. A painted surface, such as the skin of a commercial airliner, at the same absolute temperature will radiate 41 milliwatts per square centimeter. If this aluminum aircraft skin were not painted, the emissivity factor would be considerably smaller, and the radiation would be less than 4 milliwatts of power per square centimeter. As mentioned previously, IR from a source will be distributed over a good part of the spectrum, but the maximum radiation occurs at some specific wavelength. Figure 21-3 shows the dis-

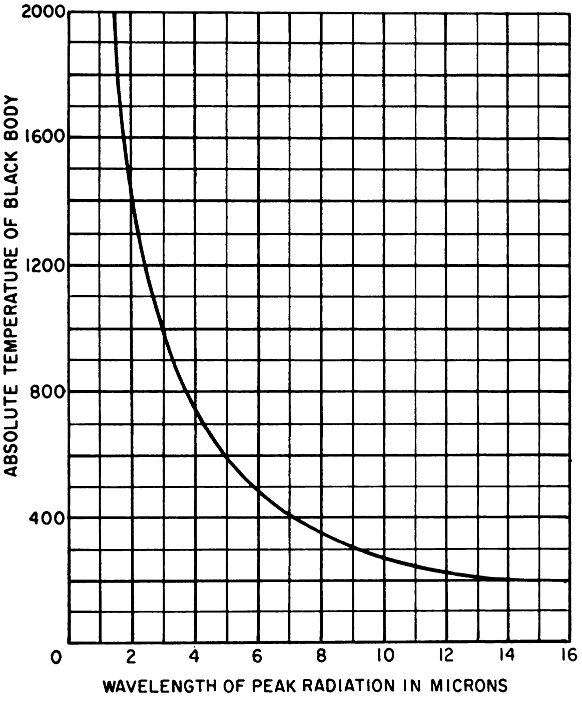

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Figure 21-2.—The wavelength of the peak radiation from a black body in relation to its temperature.

tribution of energy radiated from a black body at various temperatures.

As an example, IR from jet and rocket engine exhaust plumes is primarily due to the molecular excitation of water vapor and carbon dioxide which are characteristic byproducts of combustion. This molecular radiation peaks at 2.7 microns (due to water vapor and carbon dioxide) and 4.3 microns (due to carbon dioxide alone). In a practical situation, however, more usable radiation is obtained from the hot tailpipe and other heated surfaces.

TRANSMISSION CHARACTERISTICS

In military applications of IR systems, the transmitting medium is generally the atmosphere. The effect of the atmosphere on the transmission of IR is a very important factor in considering the overall effectiveness of the system.

Atmospheric Absorption

There are two primary causes of atmospheric attenuation: scattering by suspended solids, and absorption by free molecules. These two influences on the attenuation are additive, but the absorption is the most important factor.

The amount of scattering caused by particles depends on the relationship between the wavelength of the radiated energy and the size of the particles. If the wavelength involved is considerably shorter than the dimensions of the particles, then the scattering is just about independent of wavelength. Since this is generally the case in the IR spectrum, the attenuation due to scattering can be measured at one wavelength and then applied over a relatively wide band of wavelengths.

This technique does not work, however, with attenuation due to molecular absorption. The amount of absorption is closely connected with the wavelength. The two substances in the atmosphere which absorb the most radiation are water vapor and carbon dioxide. In both of these substances, there are several wavelength bands where the absorption is relatively large. This condition is caused by molecular resonance. (Each molecule has a "natural frequency" of vibration, or resonant frequency.)

The resonant frequencies of these molecules are in the infrared region, and their structure is such that this natural vibration creates an oscillation of electric charge in the molecules which increases the absorption. At low altitudes, where the atmosphere is more dense, this absorption is so great that in some wavelength bands the percentage of radiation transmitted drops rapidly to zero. Between these absorption bands are areas where the atmospheric attenuation is not so great. These transmission bands are called "windows." The transmission windows in the atmosphere are approximately as shown in table 21-2.

Figure 21-4 shows the transmission characteristics of the atmosphere at two different altitudes. It will be noted by reference to figure 21-4 that the 2.7 and 4.3 micron radiation readings from a jet exhaust plume occur at frequencies of high absorption. The radiation resulting from hot tailpipe surfaces is a function of tailpipe material and temperature, usually peaking at about 3.5 microns. This frequency is in the region of an atmospheric window or low absorption band. It will also be noted that the absorption bands are much narrower at high altitudes due to the thinner atmosphere. These absorption bands will, therefore, be of lesser consideration in the design of high altitude systems.

OPTICAL DEVICES

Because of the similarity between infrared and visible light, optical devices are usually employed to gather and focus the infrared radiation upon the detector. A simplified infrared optical arrangement is shown in figure 21-5. This illustration shows a simple optical system which could be used to focus IR radiation. The entire system is enclosed within a protective housing to protect the detector and optical system from the weather. The dome is a continua-

Table 21-2.—Wavelength limits of IR transmission windows in the atmosphere.

0.95 - 1.05	microns
1.2 - 1.3	microns
1.5 - 1.8	microns
2.1 - 2.4	microns
3.0 - 5.0	microns
8.0 -12.0	microns

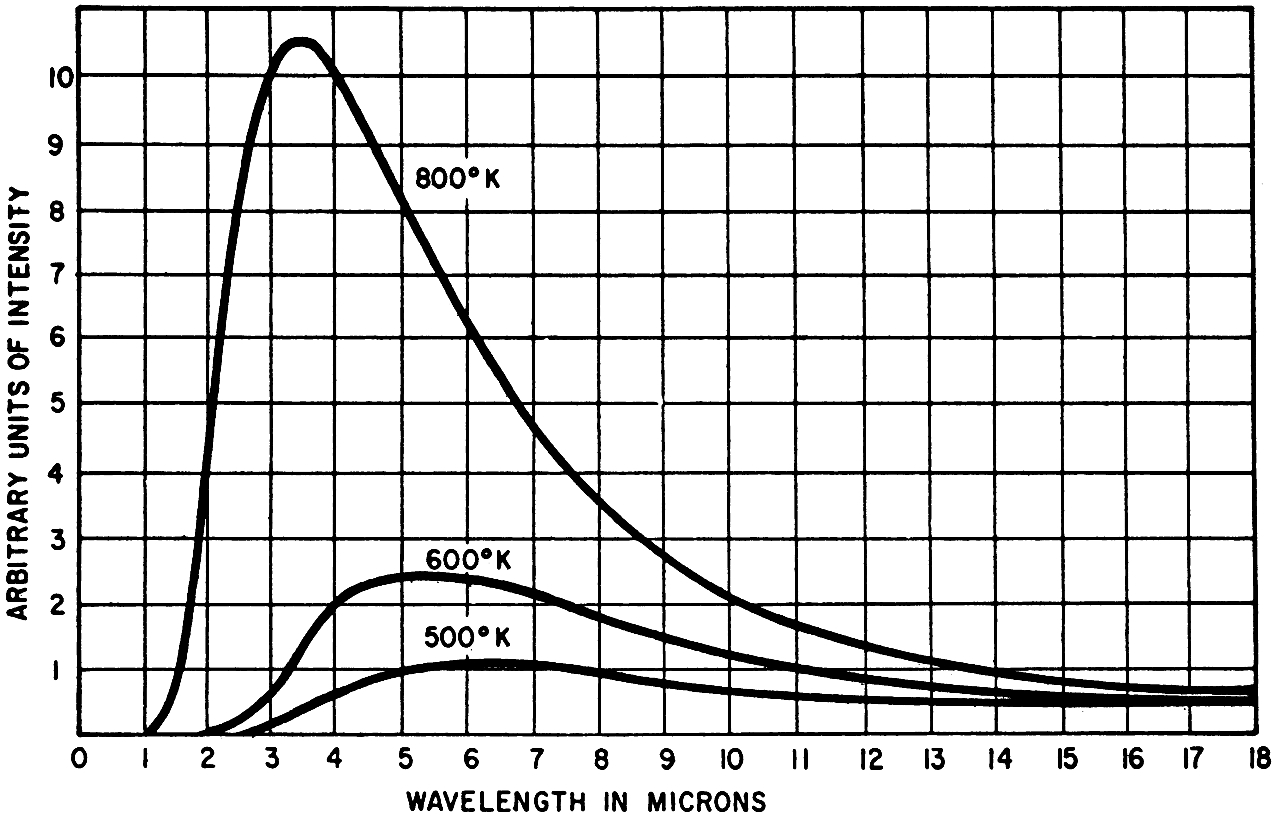

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Figure 21-3.—IR distribution curves for a black body at various temperatures.

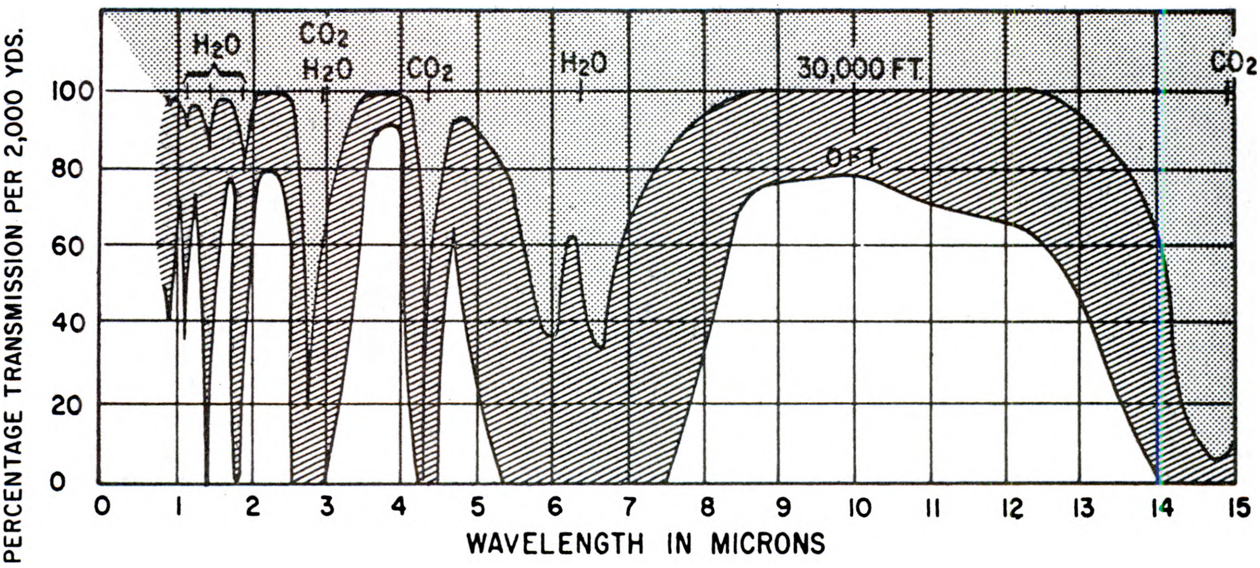

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Figure 21-4.—Atmospheric transmission characteristics.

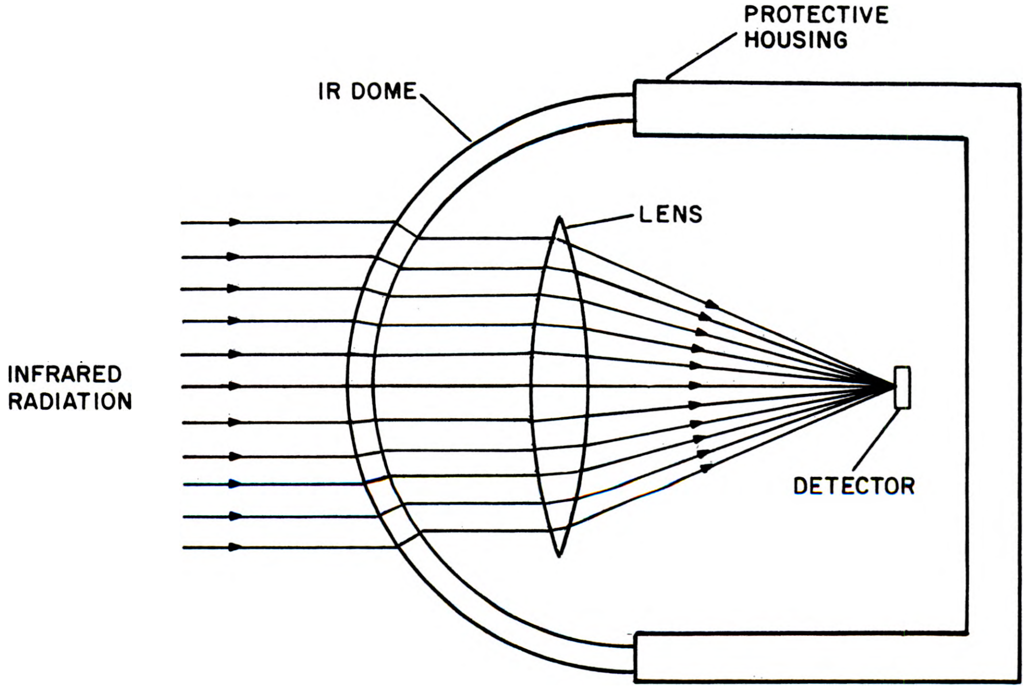

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Figure 21-5.—Simple IR optical arrangement.

tion of the protective housing and must be able to pass infrared radiation easily.

Typical materials from which domes are fabricated include glass, quartz, synthetic sapphires, germanium, and silicon. The transmission coefficient of the optical material is an important factor in the design of infrared equipment. For NIR, and generally for IIR, glass and quartz are satisfactory. Figure 21-6 shows that glass, quartz, and synthetic sapphires have excellent transmission characteristics in the visible and near infrared regions. They cut off sharply in the middle infrared region. Optical glass is completely opaque to wavelengths longer than 3 microns, quartz cuts off at 4 microns, and synthetic sapphire loses its transparency at wavelengths greater than 6 microns.

Germanium and silicon are semiconductor materials which are opaque to visible light and transparent throughout most of the near and middle infrared regions.

A wholly different type of optics is required for FIR. Single crystals of silver chloride, rolled flat, are satisfactory windows for the transmission of FIR. Sodium chloride (rock salt), grown in single crystals and cut and ground into a lens or window, is excellent. However, rock salt is highly soluble in water and must be protected from the atmospheric moisture. Therefore, rock salt is not practical to use as an IR dome material.

There are a number of problems involved in the design of IR optical systems. The material used must match the wavelength to which the detector will respond. Optical materials are generally weak physically, and many have a low resistance to high temperature and thermal shock. Chemical reactions and pressure will change the properties of some materials.

Another vital problem is that of system heating. If any part of the system becomes heated by energy it has absorbed, this energy will be reradiated at wavelengths that differ from those of the original radiation. If the detector is sensitive to these new wavelengths,

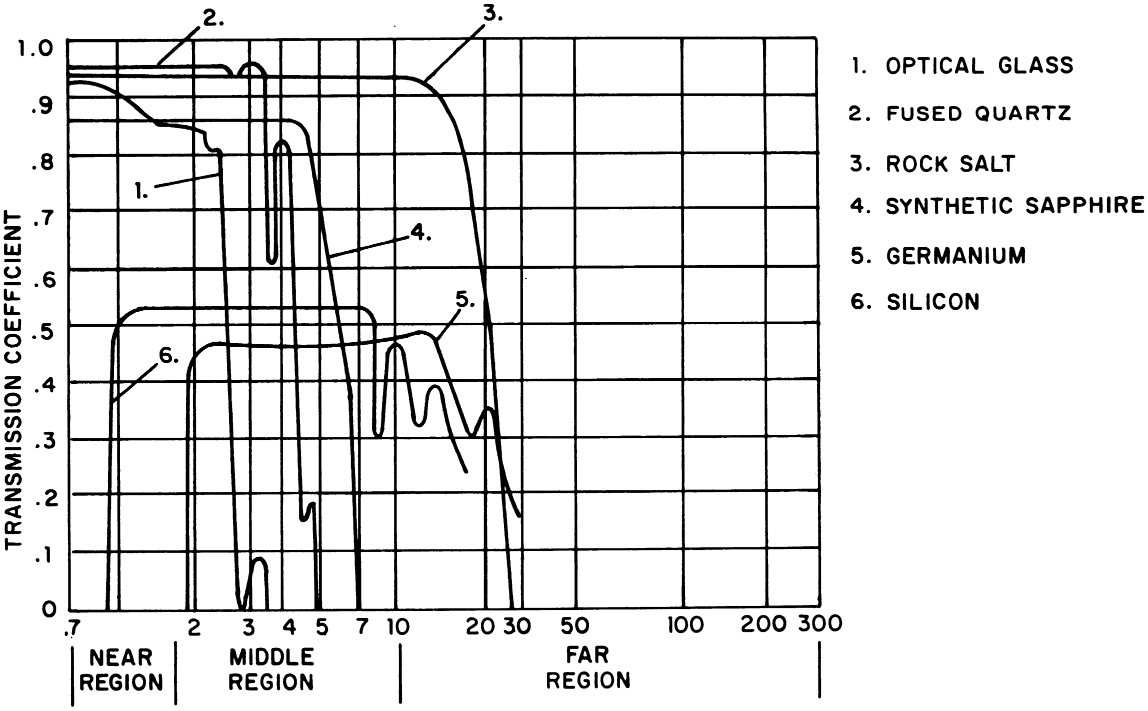

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Figure 21-6.—Wavelength vs. transmission coefficient.

this source which is much closer than the target will obscure the target or cause "ghost" images.

Attenuation in optical materials is primarily due to two things: surface reflections, usually overcome by antireflection coatings; and attenuation by the material. The latter is the more serious problem.

IR systems often have a chopping reticle in the principal focal plane. The chopper is generally a rotating disk with some clear and some opaque areas. Although a chopper is not absolutely necessary in a search system, it has several useful properties. The chopping rate furnishes a conveniently high carrier frequency for the electronic amplifiers. The reticle pattern can operate as a discriminator or filter. For example, it can be designed for the type of backgrounds expected in order to provide better differentiation of target and background.

Optical filters are used in IR instruments to isolate certain wavelength regions of interest, such as atmospheric windows, and to screen out undesired wavelengths. Three general types of filters are as follows:

1. Those which pass short waves.
2. Those which pass a particular band of waves.
3. Those which pass long waves.

DETECTORS

The most critical component of any IR system is the detector. The characteristics of the atmosphere and the source, if it is a military target, cannot be changed. Optical materials are somewhat standardized, as are display devices and control circuits. Although research and development in the last decade has resulted in some very good all-round detectors, it is still necessary to use care in choosing the proper one for a particular application.

Many variables must be considered in the choice of a detector. The characteristics of the radiation involved will determine which type of detector will best fit the needs of the system.

DETECTOR CHARACTERISTICS

In order to compare the relative merits of different detectors in different situations, it is necessary to introduce several parameters of detector operation. These parameters make it possible to discuss the characteristics of a particular detector in terms which can be applied to any detector.

Responsivity

When IR strikes a detector material, either photoelectric or thermal, a change takes place which produces an electrical output signal, indicating that the material has been exposed to IR. The amount of signal produced by each unit of input radiation intensity is called the responsivity (R) of the detector, and is expressed as

$$R = \frac{\text{output}}{\text{input}}$$

generally in volts per watt. Many factors influence the responsivity, such as temperature of the detector and source, detector area, spectral distribution of the radiation, detector time constant, etc.

Spectral Response

One important influence on the responsivity of a detector is the change in detector sensitivity with changes in the wavelength of received radiation. The spectral limit of responsivity is considered to be the wavelength where the responsivity is half that of its maximum value. Since the spectral response is a nonlinear characteristic, it must be known for each wavelength considered, and any discussion of values must include the details of the conditions involved.

Time Constant

In any IR scanning system, the time constant of the detector must be such that the detector can fully respond before the radiation intensity changes. The time constant is considered to be the time required for the detector to develop 63 percent of its maximum output signal. The maximum scanning rate is dependent upon this time constant.

Noise

Noise exists in any circuit that carries current. Most outside noises can be eliminated or drastically reduced by shielding and proper design, but thermal noise is an ever-present problem.

Power supplies employed with IR detectors must be extremely well filtered. Since the IR radiation received by the detector is very small, noise of any appreciable amount could be sufficient to mask weak IR signals or cause false targets. Transistors, for an example, are useless in IR amplifiers because of their inherent noise characteristics.

Many different types of noise are generated within IR systems. Among these, the most important are as follows:

1. Current noise, caused by bias currents within the detector.
2. Johnson (thermal) noise, caused by thermal fluctuations in the detector material.

At low bias voltages, current noise is negligible and the output noise voltage consists almost entirely of Johnson noise. The current noise increases linearly with bias voltages and may eventually become the primary source of noise.

NOISE EQUIVALENT POWER.–Another useful and important detector parameter is the noise equivalent power (NEP) of a detector. NEP is the radiation power in watts which must strike a detector to produce a signal response from the detector equal to the noise output (in other words, signal to noise ratio of 1) over a reference bandwidth.

When comparing two different IR detectors, the one with the lower NEP has the higher useful sensitivity. Since this tends to be confusing, another parameter is used–the detectivity. This figure is simply the reciprocal of the given NEP of a detector, so that the higher detectivity a cell has, the higher is its useful output. For example, a detector with an NEP of 4.0×10^{-9} will have a detectivity of 2.5×10^{8}.

The best IR detector would be one having the greatest possible responsivity, the widest possible spectral response within the frequency band of interest, and the lowest possible NEP (or highest possible detectivity). A properly chosen detector, with the necessary operating conditions, might have a maximum range of 90 miles with a signal to noise ratio of 5 from a 1 square meter target at 300° Kelvin. This range is equivalent to an ability to detect IR emitted by a cubic inch of ice at 3 miles.

PHOTODETECTORS

The three major types of photodetectors are photoconductive, photovoltaic, and photoemissive. Signal to noise ratio of the detector is the limiting factor in determining its effectiveness. These are used in the near infrared spectrum.

Photoconductors use a semiconductor crystal that absorbs the photon energy from the radiation which strikes the surface of the crystal, changing its resistance or conductivity. Quite a number of materials have been used for this type of photodetector, including lead sulfide, lead telluride, lead selenide, cadmium sulfide, and many others. Gold-doped germanium has been established as a good detector material, but some difficulties, such as the long time constant, must be considered.

Photovoltaic cells are similar to solar cells. These are semiconductors with a high resistance photosensitive barrier between the two layers. When exposed to IR, this cell builds up a potential difference between the two layers.

Photoemissive cells operate on the principle that electronic emission is caused by exposing the cathode to IR. In this type of emission, the number of electrons emitted depends on the intensity of the IR striking the cathode.

THERMAL DETECTORS

Thermal detection is accomplished by sensing the change in temperature of the detector material as a result of IR striking its surface. There are three different types of sensing elements employed in modern detectors to sense this temperature change. These are as follows:

1. The thermopile, which is a series combination of several thermocouples.
2. Bolometers, which sense the change in resistance of the detector material.
3. Pneumatic cells, which use the expansion of a gas as an indicator.

Thermocouple

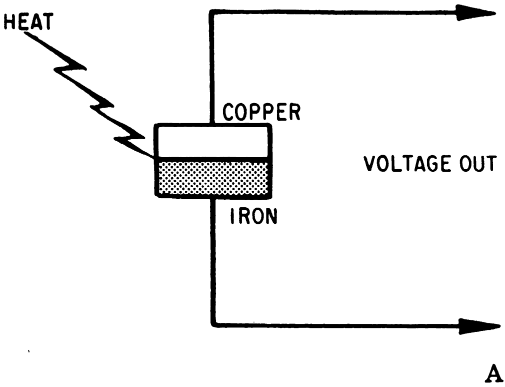
One of the basic heat detectors is the thermocouple. When two dissimilar metals such as iron and copper are joined together and heat is applied to the junction, a measureable voltage will be generated between them. Figure 21-7 shows a basic thermocouple.

The voltage difference between two metals is quite small, but the sensitivity can be increased to a point at which the thermocouple becomes useful as a detector of IR. The increase in sensitivity is obtained by connecting or stacking a number of thermocouples in series, so that they form what is known as a thermopile. The complete thermopile action is similar to that obtained when a number of flashlight cells are connected in series; that is, the output of each individual thermocouple is added to the output of the others. Thus, ten thermocouples, with individual output voltages of 0.001 volt, would have a total output of 0.010 volt when connected in series.

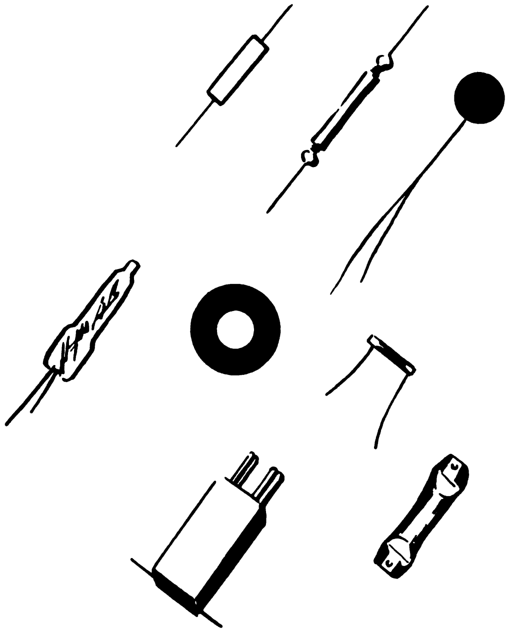
The effective sensitivity of a thermopile can be further increased by mounting it at the focal point of a parabolic reflector. When this method is used, IR given off by the target is focused on the thermopile by the reflector.

Bolometers

A bolometer is a very sensitive material whose resistance will vary, depending on the amount of IR to which it is exposed. There are two main classes of bolometers – barretters and thermistors.



AQ.254
Figure 21-7.—Thermocouple.



AQ.255
Figure 21-8.—Various thermistors.

A barretter consists of a short length of very fine wire (usually platinum) which has a positive temperature coefficient. (A substance has a positive temperature coefficient if its resistance increases with temperature, and a negative coefficient if its resistance decreases with an increase in its temperature.)

The thermistor is a type of variable resistor made of semiconducting material, such as oxides of manganese, nickel, cobalt, selenium, and copper. The thermistor has a negative temperature coefficient of resistance. Thermistors are made in the form of beads, disks, rods, and flakes, some of which are shown in figure 21-8.

The heat sensitive materials of thermistors are mixed in various proportions to provide the specific characteristics of resistance versus temperature necessary for target detection.

Figure 21-9 shows the change in resistance which can be produced in a typical thermistor material and in a barretter. This comparison shows that the thermistor has the steeper temperature coefficient of resistance curve, and therefore is the more sensitive of the two sensors.

One simple type of infrared detector consists of two thin strips of platinum which are used to form two arms of a Wheatstone bridge. To increase the thermal sensitivity of the strips, each is blackened on one side. The IR to be measured is applied to one of the strips, and is absorbed by its blackened surface. As the strip absorbs heat, its resistance changes and unbalances the bridge. The imbalance causes a change in current produced by an external voltage applied to the input terminals of the bridge.

A device of this kind is shown in figure 21-10. It consists of four nickel strips supported by mounting bars, which have electrical leads attached to them. A silvered parabolic reflector (mirror) is used to focus the IR on the nickel strips. The change of resistance in the strips produces unbalanced conditions in the bridge circuit which can be used to produce correction signals.

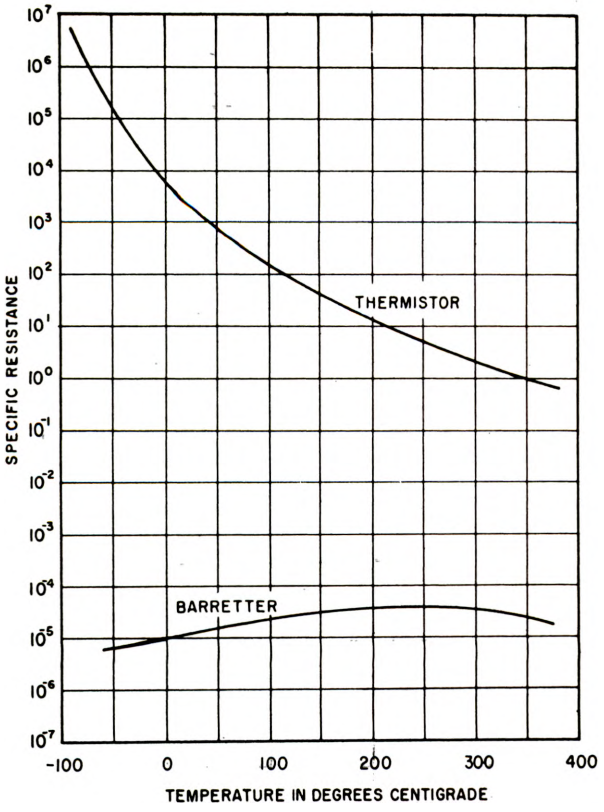


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Figure 21-9.—Comparison of thermistor and barretter sensitivity.

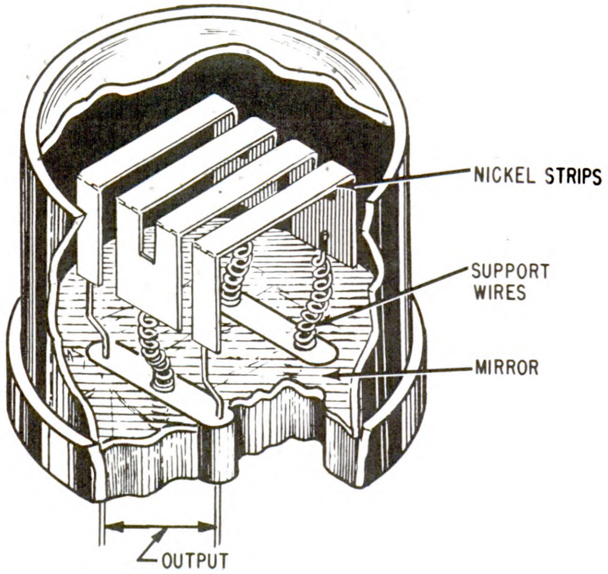

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Figure 21-10.—Infrared detecting device.

Pneumatic Cell

Another unique infrared detector is the pneumatic cell or GOLAY detector shown in figure 21-11. This detector is actually a miniature heat engine.

Infrared energy entering the window causes expansion of a volume of gas located between the reflecting diaphragm and the window. The lamp at the after end of the detector emits a light beam which is focused by the lens and then passes through the grid and onto the reflecting diaphragm. The expansion and contraction of the gases between the window and diaphragm will cause the diaphragm to change its shape in response to changes in the amount of infrared energy entering the window.

Changes in shape of the diaphragm will cause its light-reflective properties to vary accordingly, modulating its light output. The light reflected from the diaphragm will then pass back through the grid which is designed to in-

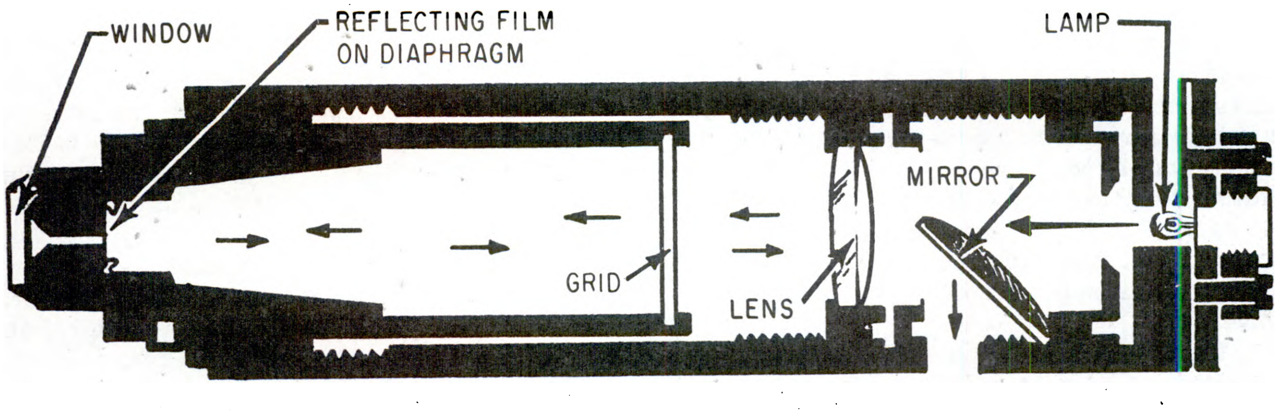


Figure 21-11.—Golay detector.

tensify the variations of the reflected light. After passing through the grid, some of the light strikes the mirror and is reflected to a photocell of high sensitivity (not shown in the figure). The modulated output of the photocell is a voltage proportional to the intensity of the IR entering the window.

The Golay detector has the most rapid response of any infrared detector, but it can operate only when radiant heat is received intermittently. An optical chopper may be used to interrupt the flow of IR to the cell periodically. Another advantage of the Golay detector is its extremely wide bandwidth, making it a very good choice for use in IR spectrum analysis.

APPLICATIONS

Military and industrial applications of IR have grown in number considerably in the last decade. A complete discussion of all applications would be beyond the scope of this manual. However, some of the systems and concepts applicable to military situations are discussed in the following paragraphs.

MILITARY USES OF INFRARED

Infrared devices found their first military uses during World War II as a snooperscope which operated in total darkness and outlined enemy troops by the heat radiated from their bodies. A rifle with a device known as the sniperscope made it possible to see a target in total darkness and fire with normal accuracy without the enemy becoming aware of one's presence.

Since infrared is invisible but behaves much like visible light (that is, it can be reflected and controlled in a beam pattern), it has served as a means of communication for specific wartime purposes. Development of equipment which would receive the invisible light was the foundation for the design and successful use of some highly important weapons. Infrared, when used for short-range communication between sea-level stations, such as ships, affords excellent security. Infrared rays are limited to line of sight, and are rapidly attenuated at sea level; thus, IR acts in favor of security for short-range communications. Military use of infrared for communications therefore requires a powerful source that can be modulated and sensitive receivers for detecting the modulated source. Such sources and receivers have been developed for near infrared energy.

Infrared is used in photography as it is effective against camouflaged targets. Night photography using infrared can produce a better visual presentation of terrain than the best mapping radar.

Infrared has invaded the navigation field. Groundspeed indicators are being developed that will compete with Doppler radar. Anticollision circuits are under experimentation.

IR is also used in image forming devices, thermal or ship detection, and infrared radar. The portable infrared detector (PID) is a passive far infrared (FIR) equipment used for the detection of personnel, vehicles, tanks, small boats, and ships. It detects the difference in temperature between a body and its immediate background and provides an audible signal output. A larger far infrared system for ship detection is the stabilized ship detector (SSD). This provides a permanent record of the true bearing of all targets that are detected within the angle scanned. Infrared radar uses a pulsed IR source and receives reflected IR energy as in microwave radar.

Infrared has excellent application to guided missiles. Military targets, such as ships, factories, and aircraft, are normally warmer than their surroundings. The presence of these targets may be detected by the heat radiation they emit. The radiation of heat at lower temperatures is particularly important in the passive detection of surface targets, since there is no economical way by which the enemy can camouflage his self-radiated heat.

The Felix bomb was the first guided missile to utilize IR. It was automatically guided by an infrared homing device in the nose of the bomb. The Felix bomb was thoroughly tested and declared reliable and adequate for operational use, but World War II ended before it could be used under combat conditions. This opened the way to a new and different method of guidance, infrared homing.

Homing guidance systems control the path of the missile by a device in the missile that reacts to some distinguishing feature of the target. They are the most accurate of all guidance systems. Homing systems are divided into the following three types, depending upon the source of target radiations:

1. Active homing—both the source which illuminates the target and the receiver which detects the echoes are carried in the missile.
2. Semiactive homing—the target is illuminated by some source outside the missile and the missile receiver utilized the target reflections.
3. Passive homing—the missile receiver detects the natural radiation of the target.

Active and semiactive types generally use radar, whereas passive types use heat or light, or in some cases, home on a radio or radar transmitter.

The Sidewinder is probably the simplest and cheapest of all guided missiles. It uses an infrared homing system and is designed to destroy high-performance aircraft from sea level to about 50,000 feet.

The experimental Midas satellite, which was launched by the United States, employs infrared principles. It is equipped with an infrared scanning device capable of instantaneous spotting and reporting of the launching of a hostile ballistic missile. It is expected to provide complete and constant scanning of the earth's surface. Flashing an alarm of the blast-off of enemy missiles, would give the United States 30 minutes to prepare for nuclear bombardment.

While it is unlikely that radar will ever be entirely replaced by IR, it is already an established fact that IR possesses certain advantages over radar. It is expected that radar and IR will work as a team in many applications, such as fire control, guidance, and even search.

APPENDIX I

FORMULAS

Ohm's Law for D-C Circuits

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2R$$

Resistors in Series

$$R_T = R_1 + R_2 + \ldots$$

Resistors in Parallel

Two resistors

$$R_T = \frac{R_1R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

RL Circuit Time Constant

$$\frac{L \text{ (in henrys)}}{R \text{ (in ohms)}} = t \text{ (in seconds), or}$$

$$\frac{L \text{ (in microhenrys)}}{R \text{ (in ohms)}} = t \text{ (in microseconds)}$$

RC Circuit Time Constant

R (ohms) x C (farads) = t (seconds)

R (megohms) x C (microfarads) = t (seconds)

R (ohms) x C (microfarads) = t (microseconds)

R (megohms) x C (micromicrofarads) = t (microseconds)

Capacitors in Series

Two capacitors

$$C_T = \frac{C_1C_2}{C_1 + C_2}$$

More than two

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

Capacitors in Parallel: $C_T = C_1 + C_2 + \ldots$

Capacitive Reactance: $X_C = \frac{1}{2\pi fC}$

Impedance in an RC Circuit (Series)

$$Z = \sqrt{R^2 + (X_C)^2}$$

Inductors in Series

$L_T = L_1 + L_2 + \ldots$ (No coupling between coils)

Inductors in Parallel

Two inductors

$L_T = \frac{L_1L_2}{L_1 + L_2}$ (No coupling between coils)

More than two

$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots$ (No coupling between coils)

Inductive Reactance

$$X_L = 2\pi fL$$

Q of a Coil

$$Q = \frac{X_L}{R}$$

Impedance of an RL Circuit (Series)

$$Z = \sqrt{R^2 + (X_L)^2}$$

Impedance with R, C, and L in Series

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Parallel Circuit Impedance

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Sine-Wave Voltage Relationships

Average value

$$E_{ave} = \frac{2}{\pi} \times E_{max} = 0.637E_{max}$$

Effective or r.m.s. value

$$E_{eff} = \frac{E_{max}}{\sqrt{2}} = \frac{E_{max}}{1.414} = 0.707E_{max}$$
$$= 1.11E_{ave}$$

Maximum value

$$E_{max} = \sqrt{2}(E_{eff}) = 1.414E_{eff}$$
$$= 1.57E_{ave}$$

Voltage in an a-c circuit

$$E = IZ = \frac{P}{I \times P.F.}$$

Current in an a-c circuit

$$I = \frac{E}{Z} = \frac{P}{E \times P.F.}$$

Power in A-C Circuit

Apparent power: $P = EI$

True power: $P = EI \cos\theta = EI \times P.F.$

Power Factor

$$P.F. = \frac{P}{EI} = \cos\theta$$

$$\cos\theta = \frac{\text{true power}}{\text{apparent power}}$$

Transformers

Voltage relationship

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \text{ or } E_s = E_p \times \frac{N_s}{N_p}$$

Current relationship

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Induced voltage

$$E_{eff} = 4.44 \times BAfN \times 10^{-8}$$

Turns ratio

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

Secondary current

$$I_s = I_p \times \frac{N_p}{N_s}$$

Secondary voltage

$$E_s = E_p \times \frac{N_s}{N_p}$$

Three-Phase Voltage and Current Relationships

With wye connected windings

$$E_{line} = \sqrt{3}(E_{coil}) = 1.732E_{coil}$$

$$I_{line} = I_{coil}$$

With delta connected windings

$$E_{line} = E_{coil}$$

$$I_{line} = 1.732I_{coil}$$

With wye or delta connected winding

$$P_{coil} = E_{coil} I_{coil}$$

$$P_t = 3P_{coil}$$

$$P_t = 1.732 E_{line} I_{line}$$

(To convert to true power multiply by cos θ)

Resonance

At resonance

$$X_L = X_C$$

Resonant frequency

$$F_o = \frac{1}{2\pi\sqrt{LC}}$$

Series resonance

$$Z \text{ (at any frequency)} = R + j(X_L - X_C)$$

$$Z \text{ (at resonance)} = R$$

Parallel resonance

$$Z_{max} \text{ (at resonance)} = \frac{X_L X_C}{R} = \frac{{X_L}^2}{R}$$

$$= QX_L = \frac{L}{CR}$$

Band width

$$\Delta = \frac{F_o}{Q} = \frac{R}{2\pi L}$$

Tube Characteristics

Amplification factor

$$\mu = \frac{\Delta e_p}{\Delta e_g} \text{ } (i_p \text{ constant})$$

$$\mu = g_m r_p$$

A-c plate resistance

$$r_p = \frac{\Delta e_p}{\Delta i_p} \text{ } (e_g \text{ constant})$$

Grid-plate transconductance

$$g_m = \frac{\Delta i_p}{\Delta e_g} \text{ } (e_p \text{ constant})$$

Decibels

NOTE: Wherever the expression "log" appears without a subscript specifying the base, the logarithmic base is understood to be 10.

Power ratio

$$db = 10 \log \frac{P_2}{P_1}$$

Current and voltage ratio

$$db = 20 \log \frac{I_2 \sqrt{R_2}}{I_1 \sqrt{R_1}}$$

$$db = 20 \log \frac{E_2 \sqrt{R_1}}{E_1 \sqrt{R_2}}$$

NOTE: When R_1 and R_2 are equal they may be omitted from the formula. When reference level is one milliwatt

$$dbm = 10 \log \frac{P}{0.001} \text{ (when P is in watts)}$$

Synchronous Speed of Motor

$$r.p.m. = \frac{120 \text{ x frequency}}{\text{number of poles}}$$

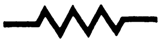
Comparison of Units in Electric and Magnetic Circuits

	Electric circuit	Magnetic circuit
Force	Volt, E, or e.m.f.	Gilberts, F, or m.m.f.
Flow	Ampere, I	Flux, Φ, in maxwells
Opposition	Ohms, R	Reluctance, $\mathcal{R}$
Law	Ohm's law, $I = \frac{E}{R}$	Rowland's law, $\Phi = \frac{F}{\mathcal{R}}$
Intensity of force	Volts per cm. of length.	$H = \frac{1.257IN}{L}$, gilberts per centimeter of length.
Density	Current density—for example, amperes per cm^2.	Flux density—for example, lines per $cm.^2$, or gausses.

APPENDIX II

SYMBOLS

RESISTORS:



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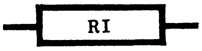
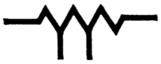
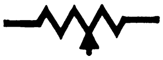


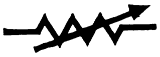
GENERAL



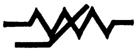
TAPPED



ADJUSTABLE
TAP

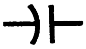


CONTINUOUSLY
VARIABLE

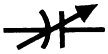


NONLINEAR

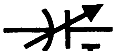
CAPACITORS:



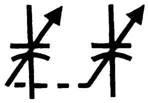
FIXED



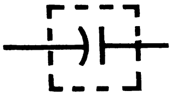
VARIABLE



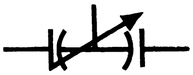
TRIMMER



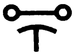
GANGED



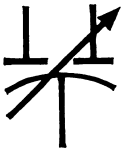
SHIELDED



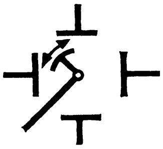
SPLIT-STATOR



FEED-THROUGH



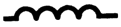
DIFFERENTIAL



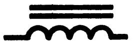
PHASE SHIFT

(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC, THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

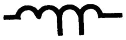
INDUCTIVE COMPONENTS:



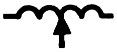
GENERAL



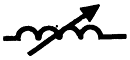
MAGNETIC
CORE



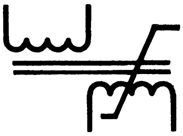
TAPPED



ADJUSTABLE

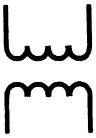


ADJUSTABLE OR
CONTINUOUSLY
ADJUSTABLE

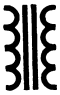


SATURABLE
CORE REACTOR

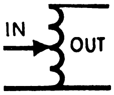
TRANSFORMERS



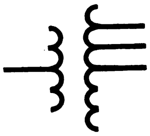
GENERAL



MAGNETIC CORE
TRANSFORMER

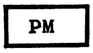


AUTOTRANSFORMER

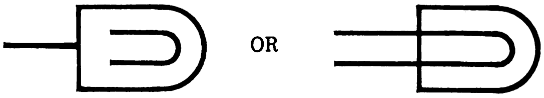


WITH TAPS,
SINGLE-PHASE

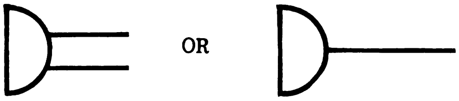
PERMANENT MAGNET



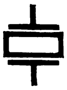
INDICATOR LAMP



MICROPHONE

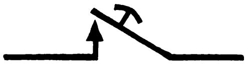


CRYSTAL



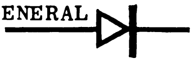
QUARTZ CRYSTAL; PIEZOELECTRIC CRYSTAL UNIT.

KEY

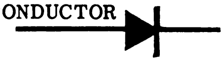


RECTIFIER

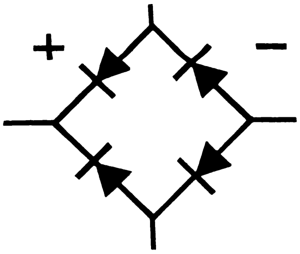
GENERAL



SEMICONDUCTOR

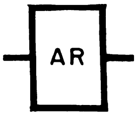


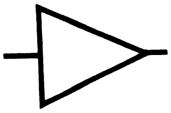
NORMAL CURRENT FLOW IS AGAINST THE ARROW



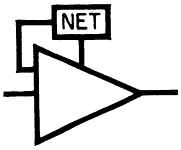
FULL WAVE BRIDGE TYPE

AMPLIFIER





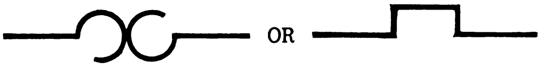
TRIANGLE POINTS IN DIRECTION OF TRANSMISSION (SIGNAL FLOW)



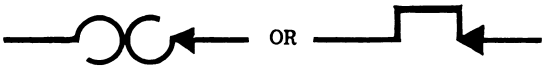
AMPLIFIER WITH EXTERNAL FEEDBACK PATH

BASIC SYMBOL INDICATES ANY METHOD OF AMPLIFICATION EXCEPT THAT OPERATING ON THE PRINCIPLE OF ROTATING MACHINERY.

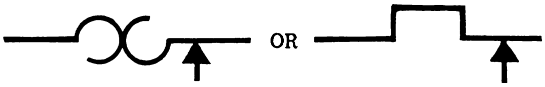
THERMAL ELEMENTS

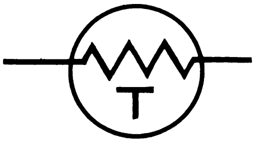


THERMAL RELAY WITH NORMALLY CLOSED CONTACT.

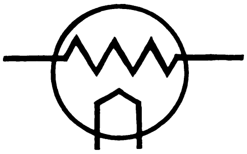


FLASHER; THERMAL CUTOUT

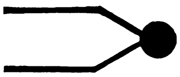




THERMISTOR

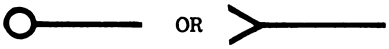


WITH INTEGRAL HEATING ELEMENT

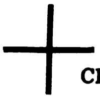


TEMPERATURE-MEASURING THERMOCOUPLE (DISSIMILAR METAL DEVICE)

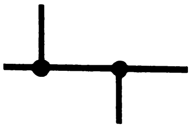
INPUTS (NONSTANDARD)



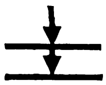
PATH, TRANSMISSION



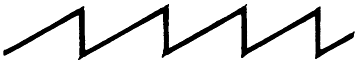
CROSSING NOT CONNECTED



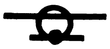
JUNCTION CONNECTED



TWISTED PAIR

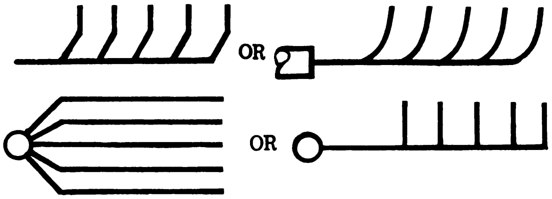


AIR OR SPACE PATH



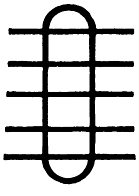
COAXIAL

GROUPING OF WIRES IN BUNDLES

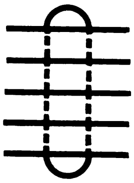


GROUPING OF WIRES IN CABLES

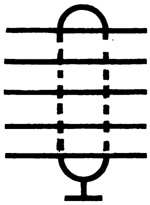
CABLES



FIVE-CONDUCTOR CABLE



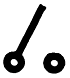
SHIELDED FIVE-CONDUCTOR CABLE



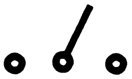
GROUNDED SHIELD

NUMBER OF CONDUCTORS MAY BE ONE OR MORE AS NECESSARY

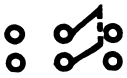
SWITCHES



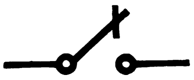
GENERAL (SINGLE THROW)



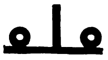
GENERAL (DOUBLE THROW)



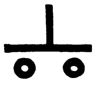
TWO POLE DOUBLE THROW SWITCH



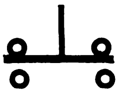
KNIFE SWITCH



PUSHBUTTON (BREAK)

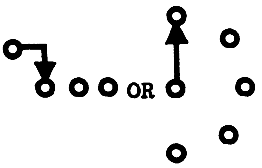


PUSHBUTTON (MAKE)



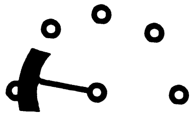
PUSHBUTTON TWO CIRCUIT

SELECTOR SWITCHES

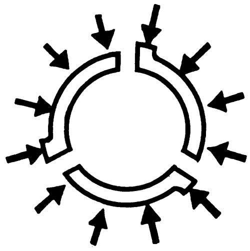


GENERAL

ANY NUMBER OF TRANSMISSION PATHS MAY BE SHOWN. ALSO BREAK BEFORE MAKE SWITCH.



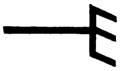
MAKE BEFORE BREAK



WAFER, TYPICAL 3-POLE, 3-CIRCUIT SWITCH. VIEWED FROM END OPPOSITE CONTROL KNOB. FOR MORE THAN ONE SECTION, #1 IS NEAREST CONTROL KNOB.

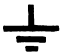
CIRCUIT RETURNS

CHASSIS CONNECTION



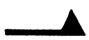
(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)

GROUND

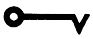


CONTACTS (ELECTRICAL)

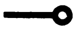
SWITCH



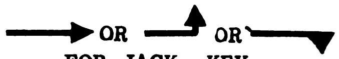
MOMENTARY SWITCH



LOCKING



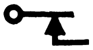
NONLOCKING

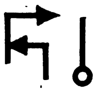


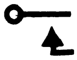
FOR JACK, KEY, RELAY, ETC.

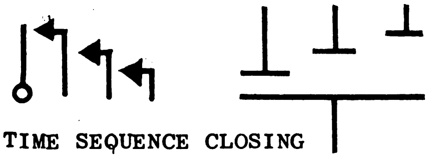
CONTACTS (ELECTRICAL) (Continued)

CONTACT ASSEMBLIES

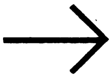

CLOSED CONTACT
(BREAK)

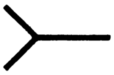

MAKE BEFORE
BREAK

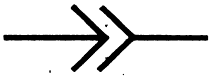

OPEN CONTACT
(MAKE)

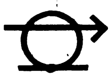

TIME SEQUENCE CLOSING

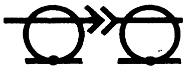
DISCONNECTING DEVICES

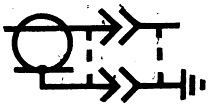

MALE
(PIN CONTACT)


FEMALE
(SOCKET CONTACT)

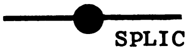

ENGAGED
(PIN-TO-SOCKET)

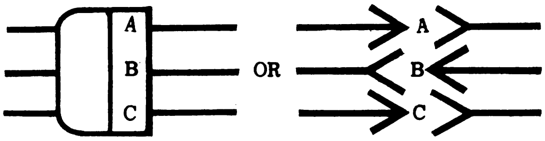

COAXIAL
(MALE)


COAXIAL CONNECTORS
MATED


COAXIAL CONNECTED
TO SINGLE CONDUCTOR

THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.

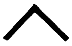

SPLICE

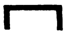


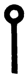
CONNECTOR ASSEMBLY (GENERAL)

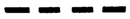
ELECTRON TUBES

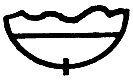
COMPONENT TUBE SYMBOLS

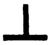

DIRECTLY-HEATED
(FILAMENTARY)
CATHODE

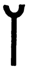

INDIRECTLY-HEATED
CATHODE

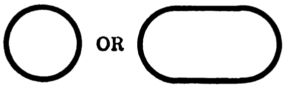

COLD
CATHODE


GRID

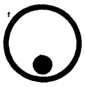

POOL CATHODE

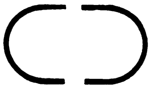

ANODE OR
PLATE


PHOTOCATHODE

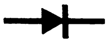


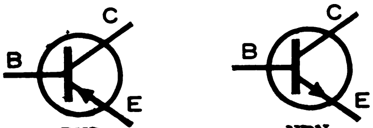
ENVELOPE (SHELL)


GAS FILLED
ENVELOPE


SPLIT ENVELOPE

SEMICONDUCTOR DEVICES

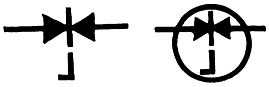

DIODE

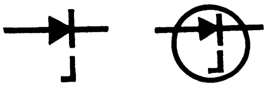


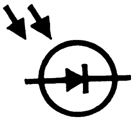
PNP

NPN

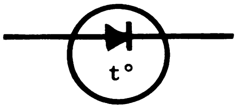
TRANSISTORS


BREAKDOWN DIODE,
BIDIRECTIONAL

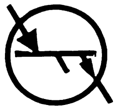

BREAKDOWN DIODE,
UNDIRECTIONAL
(ALSO BACKWARD DIODE)


PHOTODIODE

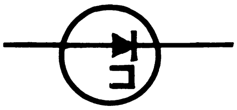
SEMICONDUCTOR DEVICES: (Continued)



TEMPERATURE
DEPENDENT DIODE

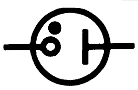


PNPN SWITCH

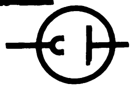


TUNNEL DIODE

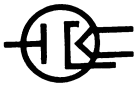
TYPICAL ELECTRON TUBES



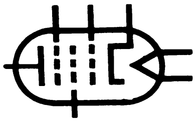
COLD CATHODE
GAS TUBE



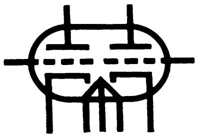
PHOTOTUBE SINGLE
UNIT, VACUUM



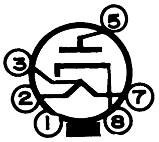
DIODE



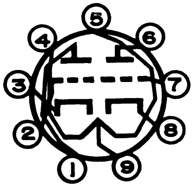
PENTODE



TWIN TRIODE
ILLUSTRATING
ELONGATED ENVELOPE

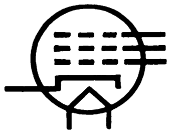


DIODE SHOWING BASE
CONNECTIONS

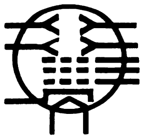


TWIN TRIODE WITH TAPPED HEATER

TYPICAL CATHODE RAY TUBES

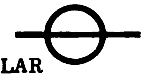


MAGNETIC DEFLECTION

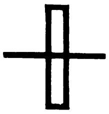


ELECTROSTATIC
DEFLECTION

WAVEGUIDES

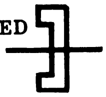


CIRCULAR

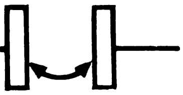


RECTANGULAR

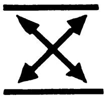
RIDGED



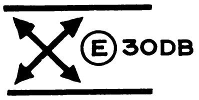
ROTARY
JOINT



DIRECTIONAL COUPLERS



GENERAL

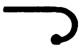


E PLANE APERTURE
COUPLING, 30 DB
TRANSMISSION LOSS

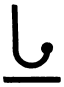
COUPLING METHODS

GENERALLY USED FOR COAXIAL
AND WAVEGUIDE TRANSMISSION.

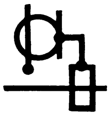
COUPLING BY APERTURE WITH AN OPENING OF LESS THAN FULL WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN CIRCLE (E, H, OR HE).



COUPLING BY LOOP TO SPACE

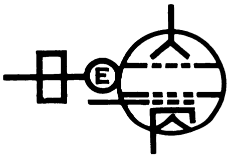


COUPLING BY LOOP TO GUIDED
TRANSMISSION PATH



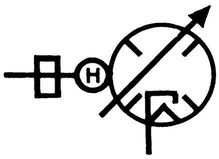
COUPLING BY PROBE FROM COAXIAL TO
RECTANGULAR WAVEGUIDE WITH DIRECT-
CURRENT GROUNDS CONNECTED

TYPICAL MAGNETRONS AND KLYSTRONS

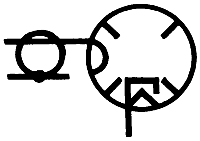


REFLEX KLYSTRON,
APERATURE COUPLED

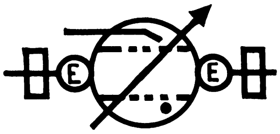
TUNABLE MAGNETRON,
APERTURE COUPLED



TYPICAL MAGNETRONS AND KLYSTRONS
(Continued)

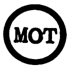


RESONANT TYPE WITH COAXIAL OUTPUT

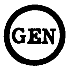


TRANSMIT-RECEIVE (TR) TUBE GAS FILLED, TUNABLE INTEGRAL CAVITY, APERTURE COUPLED, WITH STARTER

ROTATING MACHINES

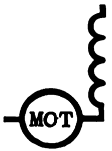


MOTOR

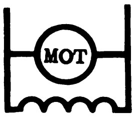


GENERATOR

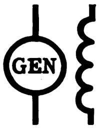
TYPES OF WINDINGS



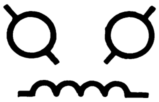
SERIES



SHUNT

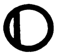


SEPARATELY EXCITED

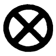


DYNAMOTOR

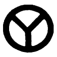
WINDING SYMBOLS



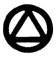
SINGLE-PHASE



TWO - PHASE



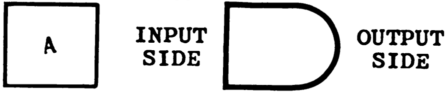
THREE-PHASE (WYE)



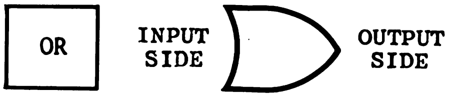
THREE-PHASE (DELTA)

LOGIC FUNCTIONS

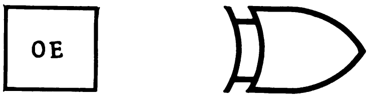
AND FUNCTION



INCLUSIVE OR FUNCTION

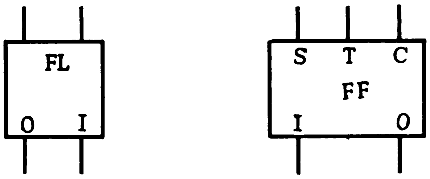


EXCLUSIVE OR FUNCTION



FLIP-FLOPS

LATCH COMPLEMENTARY



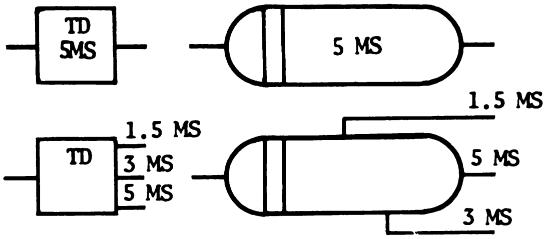
S-SET T-TRIGGER C-CLEAR

NEGATION

O

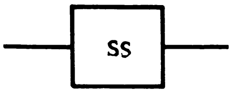
ELECTRIC INVERTER

TIME DELAY

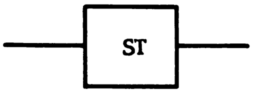


LOGIC FUNCTIONS (Continued)

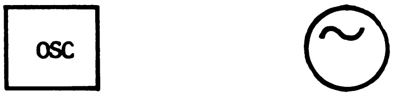
SINGLE SHOT



SCHMITT TRIGGER

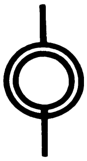


OSCILLATOR



SYNCHROS

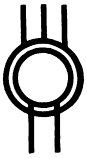
GENERAL



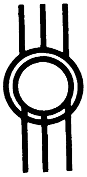
A LETTER COMBINATION FROM THE FOLLOWING LIST MAY BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

TX - TORQUE TRANSMITTER
TDX - TORQUE DIFFERENTIAL TRANSMITTER
CX - CONTROL TRANSMITTER
CDX - CONTROL DIFFERENTIAL TRANSMITTER
TR - TORQUE RECEIVER
CT - CONTROL TRANSFORMER

SYNCHROS (Continued)

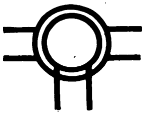


TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER

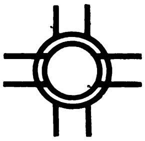


DIFFERENTIAL TRANSMITTER OR RECEIVER

RESOLVER (SYNCHRO)

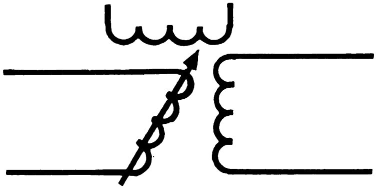


SINGLY-WOUND ROTOR

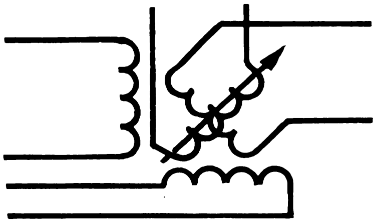


DOUBLY-WOUND ROTOR

RESOLVER

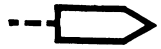


SINGLY-WOUND ROTOR

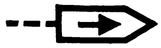


DOUBLY-WOUND ROTOR

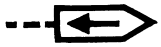
PICKUP HEADS



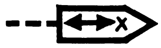
GENERAL



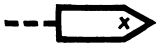
WRITING; RECORDING; HEAD,
SOUND RECORDER



READING; PLAYBACK; HEAD,
SOUND REPRODUCER

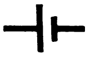


APPLICATION: WRITING, READING,
AND ERASING

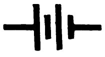


ERASING; ERASER, MAGNETIC

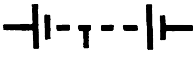
BATTERIES



ONE CELL



MULTICELL

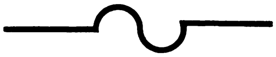


TAPPED MULTICELL

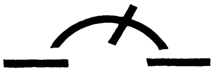
(LONG LINE IS ALWAYS POSITIVE)

CIRCUIT PROTECTORS

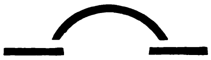
FUSE



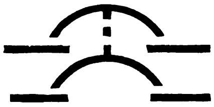
CIRCUIT BREAKERS



SWITCH

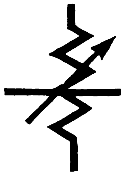


PUSH PULL OR PUSH

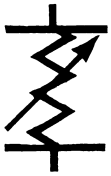


GANGED

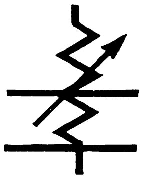
ATTENUATORS



GENERAL



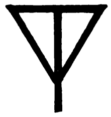
BALANCED



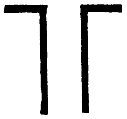
UNBALANCED

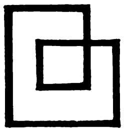
ANTENNAS

GENERAL

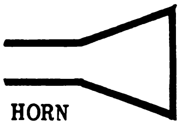


DIPOLE



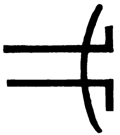


LOOP



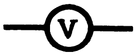
HORN

PARABOLIC



(NONSTANDARD)

METERS



A - AMMETER

CRO - OSCILLOSCOPE

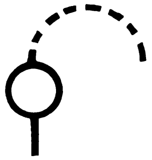
G - GALVANOMETER

MA - MILLIAMMETER

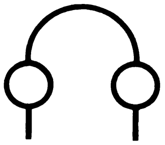
OHM - OHMMETER

V - VOLTMETER

HEADSET



OR



APPENDIX III

LAWS OF EXPONENTS

The International Symbols Committee has adopted prefixes for denoting decimal multiples of units. The National Bureau of Standards has followed the recommendations of this committee, and has adopted the following list of prefixes:

Numbers	Powers of ten	Prefixes	Symbols
1,000,000,000,000	10^{12}	tera	T
1,000,000,000	10^9	giga	G
1,000,000	10^6	mega	M
1,000	10^3	kilo	k
100	10^2	hecto	h
10	10	deka	da
.1	10^{-1}	deci	d
.01	10^{-2}	centi	c
.001	10^{-3}	milli	m
.000001	10^{-6}	micro	u
.000000001	10^{-9}	nano	n
.000000000001	10^{-12}	pico	p
.000000000000001	10^{-15}	femto	f
.000000000000000001	10^{-18}	atto	a

To multiply like (with same base) exponential quantities, add the exponents. In the language of alegebra the rule is $a^m \times a^n = a^{m+n}$

$$10^4 \times 10^2 = 10^{4+2} = 10^6$$

$$0.003 \times 825.2 = 3 \times 10^{-3} \times 8.252 \times 10^2$$

$$= 24.756 \times 10^{-1} = 2.4756$$

To divide exponential quantities, subtract the exponents. In the language of algebra the rule is

$$\frac{a^m}{a^n} = a^{m-n} \text{ or}$$

$$10^8 \div 10^2 = 10^6$$

$$3,000 \div 0.015 = (3 \times 10^3) \div (1.5 \times 10^{-2})$$

$$= 2 \times 10^5 = 200,000$$

To raise an exponential quantity to a power, multiply the exponents. In the languague of algebra $(x^m)^n = x^{mn}$.

$$(10^3)^4 = 10^{3\times4} = 10^{12}$$

$$2,500^2 = (2.5 \times 10^3)^2 = 6.25 \times 10^6 = 6,250,000$$

Any number (except zero) raised to the zero power is one. In the language of algebra $x^0 = 1$

$$x^3 \div x^3 = 1$$

$$10^4 \div 10^4 = 1$$

Any base with a negative exponent is equal to 1 divided by the base with an equal positive exponent. In the language of algebra $x^{-a} = \frac{1}{x^a}$

$$10^{-2} = \frac{1}{10^2} = \frac{1}{100}$$

$$5a^{-3} = \frac{5}{a^3}$$

$$(6a)^{-1} = \frac{1}{6a}$$

To raise a product to a power, raise each factor of the product to that power.

$$(2 \times 10)^2 = 2^2 \times 10^2$$

$$3,000^3 = (3 \times 10^3)^3 = 27 \times 10^9$$

To find the nth root of an exponential quantity, divide the exponent by the index of the root. Thus, the nth root of $a^m = a^{m/n}$.

$$\sqrt{x^6} = x^{6/2} = x^3$$

$$\sqrt[3]{64 \times 10^3} = 4 \times 10 = 40$$

APPENDIX IV

GREEK ALPHABET

Name	Capital	Lower Case	Designates
Alpha	Α	α	Angles, coefficient of thermal expansion.
Beta	Β	β	Angles, flux density.
Gamma	Γ	γ	Conductivity.
Delta	Δ	δ	Variation of a quantity, increment.
Epsilon	Ε	ϵ	Base of natural logarithms (2.71828).
Zeta	Ζ	ζ	Impedance, coefficients, coordinates.
Eta	Η	η	Hysteresis coefficient, efficiency, magnetizing force.
Theta	Θ	θ	Phase angle.
Iota	Ι	ι	
Kappa	Κ	κ	Dielectric constant, coupling coefficient, susceptibility.
Lambda	Λ	λ	Wavelength.
Mu	Μ	μ	Permeability, micro, amplification factor.
Nu	Ν	ν	Reluctivity.
Xi	Ξ	ξ	
Omicron	Ο	ο	
Pi	Π	π	3.1416
Rho	Ρ	ρ	Resistivity.
Sigma	Σ	σ	Summation symbol (cap).
Tau	Τ	τ	Time constant, time-phase displacement.
Upsilon	ϒ	υ	
Phi	Φ	φ	Angles, magnetic flux.
Chi	Χ	χ	
Psi	Ψ	ψ	Dielectric flux, phase difference.
Omega	Ω	ω	Ohms (capital), angular velocity (2 π f).

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